ENGINEERING REPORT

ON

WATER TREATMENT PLANT STUDY
MERRIMACK RIVER, MASSACHUSETTS

PREPARED FOR

NEW ENGLAND DIVISION
CORPS OF ENGINEERS
DEPARTMENT OF THE ARMY

Hayden, Harding & Buchanan, Inc.

Consulting Engineers

BOSTON, MASSACHUSETTS

MARCH 1975

HHB

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March 10, 1975

NEDSD-P-6

Colonel Charles J. Osterndorf
Deputy Division Engineer
New England Division, Corps of Engineers
Department of the Army
424 Trapelo Road
Waltham, Massachusetts 02154

Re: Contract No. DACW33-74-C-0093

Dear Colonel Osterndorf:

In accordance with the terms and conditions of the referenced contract, we have conducted an engineering study into the determination of water treatment unit processes necessary to delivery a high quality drinking water supply utilizing the Merrimack River as a source. The technical report containing our findings and conclusions is transmitted herewith.

The study considered the processes necessary for three water conditions; namely, existing water quality, anticipated water quality following implementation of the planned State-Federal Pollution Abatement Schedule, and expected water quality if goals of the 1972 Amendment to the Water Quality Act are met. Costs were estimated for the construction, operation, and maintenance of the various

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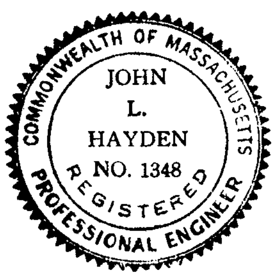
individual unit processes as well as the total treatment plant for sizes of facilities ranging from 10 million gallons per day to 500 million gallons per day.

The determination of processes recommended for inclusion in the proposed facility was made on the basis of limited field investigations, available information on water treatment and best professional judgement. Experience in the treatment of water from the Merrimack River at existing facilities was heavily relied upon to support assumptions and strengthen conclusions.

Respectfully submitted,

HAYDEN, HARDING & BUCHANAN, INC.



By

John L. Hayden
President

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CONCLUSIONS and RECOMMENDATIONS

As a result of our investigations, we have reached the following conclusions:

1. Increasing the treatment of waste effluents, while improving the aesthetic aspects of river quality, will have little effect on the construction, operation, and maintenance costs of a water treatment plant.

2. Chemical treatment, sedimentation, and filtration processes are the minimum unit operations necessary to provide a potable water supply.

3. Contact with activated carbon should be utilized to assure removal of tastes, odors, viruses and other organic substances.

4. Ozonation should be provided to reduce costs of other chemicals and to improve the disinfecting capability of the treatment facility.

From these conclusions and based on the findings of our investigations, we make the following recommendations:

1. That the processes and operations, contemplated for inclusion in the design of a treatment facility to produce high quality potable water using the Merrimack River as a source of supply, should be tested in a pilot plant study to determine operating parameters and efficiencies.

2. The proposed treatment plant should include the following facilities:

   Intake with bar screens, travelling screens, raw water pumps and raw water flow control.
   Chemical storage and feed
   Rapid mix
   Flocculation
   Sedimentation
   Filtration
   Granular activated carbon contact

Waste treatment and disposal
Activated carbon regeneration
Ancillary facilities such as offices, laboratories and landscaping.

3. Chemical feeding facilities should be provided to feed:

   Alum
   Lime
   Potassium Permanganate
   Chlorine
   Powdered Activated Carbon
   Coagulant Aid
   Ozone

4. In order to provide maximum flexibility of treatment, chemicals should be capable of being fed at several points in the process.

SECTION I

INTRODUCTION

Development of the Merrimack River as a drinking water supply source for in-basin needs as well as out-of-basin needs is being considered as a possible measure to supplement water supply systems in eastern Massachusetts and possibly southeastern New Hampshire.(11) It is therefore necessary to determine the methods which should be used in assuring the quality of the water which would be made available.

A. SCOPE

This report discusses the various unit processes involved in treatment of water to produce a high quality drinking water using the Merrimack River in Massachusetts as a source. The processes were investigated under three water quality conditions - i.e.:

1. Existing water quality,

2. Anticipated water quality following implementation of the planned State-Federal Pollution Abatement schedule,

3. Expected water quality when goals of the 1972 Amendment to the Federal Water Quality Act are met.

B. PURPOSE

It is the purpose of this report to assess the effectiveness, both hygienic and economic, of the various unit processes. The unit processes are to be investigated for construction, operation and maintenance cost for various raw water quality conditions and for flow regimes from 10 mgd (million gallons per day) to 500 mgd.

From the investigations and assessments, a preliminary design has been prepared for a treatment plant to serve short-term (i.e. 1990) water supply needs. Pursuant to a conference on July 26, 1974 with representatives of the New England Division Corps of Engineers, the preliminary plant design was based on a capacity of 50 mgd with the location to be along the Merrimack River in Tyngsboro, Massachusetts.

C. METHODOLOGY

In the preparation of this report, the unit processes which were considered are taken from various reports, manuals, and books. Through review of available literature and visits to water treatment plants in Andover, Lowell, Lawrence, and Gloucester, Massachusetts, certain unit processes were eliminated from analyses. The reasoning for elimination of each particular unit process is discussed later in this report.

In order to develop cost analyses for the various unit processes which were deemed amenable to treatment of Merrimack River water, basic designs were prepared for treatment plants having 10, 50, 100, 250 and 500 mgd capacities. From those basic designs, quantity take-offs were made, unit costs were applied, and construction cost estimates for the various processes arrived at. A factor to account for construction contingencies was added to each of the unit cost estimates to determine the total estimated construction cost. All cost figures were advanced to an Engineering News Record Construction Cost Index of 2000. This index level occurred in mid-1974.

SECTION II

WATER QUALITY

A. REQUIRED FINISHED WATER QUALITY

The Environmental Protection Agency (EPA) is presently reviewing proposed new Federal Drinking Water Standards as authorized by the Safe Drinking Water Act. (6) There is presently no assurance what the final standards will contain, although there are available data regarding the standards as presently proposed. By and large, these data continue trends initiated by the U.S. Public Health Service in promulgating standards for evaluating the quality of drinking waters. The latest available technology and research are used to determine realistic values. The Act takes cognizance of the ongoing nature of technology and research in requiring review of the standards every three years.

The categories of allowable limits are expected to be:

1. "Maximum Allowable Limits (Health)" - Water containing substances above these limits presents unnecessary risk to the health of humans and shall not be used for drinking or culinary purposes.

2. "Maximum Allowable Limits (Esthetics)" - Water containing substances above these limits is objectionable in taste and odor, economically or esthetically inferior, or is toxic to fish or plants, and should not be used for drinking or culinary purposes if better-quality water is or can be made available. (6)

These categories are similar to the requirements of the 1962 standards.(41) Several changes are proposed in the actual limits prescribed and some shifting of constituents between categories is expected.

In order for the water industry to have a better guide on which to base judgement of water quality than the 1962 standards, the AWWA published "Quality Goals for Potable Water" in 1967. (3) These guidelines provide a measure on what constitutes a high quality water rather than just an acceptable water. On many items, the AWWA felt that it "should defer to the USPHS and the medical profession" with regard to constituents which are primarily health oriented.

The 1962 standards, the AWWA goals, and the proposed standards, as we understand them, are summarized for comparison in Table 1.

B. EXISTING RAW WATER QUALITY

A summary of statistical data on periodic sampling of water from the Merrimack River is presented in Table 2. A more complete summary is presented in Appendix A(42). The points of the river from which samples were taken and for which data are shown are: (1.) at the Lowell water treatment facilities river intake and, (2.) from below the confluence with the Concord River. (41) These points were taken as being indicative of the quality of water in the reaches of the river above Lowell and between Lowell and Lawrence.

These data show the need for treatment facilities to obtain a high quality drinking water. The constituents which have been found to exceed the porposed standards are coliform bacteria, turbidity, color, iron, manganese and cadmium. Cadmium is the only constituent found to exceed the proposed EPA standards which has not had a limit stated in the AWWA goals. No limit for cadmium was stated by the AWWA because the presence of cadmium in potable water is considered to be a health related consideration and, in matters of health, the AWWA defers to the USPHS standards for the establishment of criteria.

Since modern treatment facilities are designed and operated to produce a water at least equal to the goals established by the AWWA on a consistent basis, the treated water will be of high quality with respect to those parameters. Although typical water treatment facilities may not include specific unit processes for the removal of trace constituents such as cadmium, the levels of those constituents are often reduced during treatment. (29) The methods of treatment are discussed more fully under Sections IV and V which describe the various unit processes.

C. FUTURE RAW WATER QUALITY

At the present time there are a number of waste management facilities in various stages of planning and construction which are intended to alleviate the pollutional

TABLE 1

COMPARISON OF DRINKING WATER STANDARDS

CHARACTERISTIC	1962 USPHS Standards	1968 AWWA Recommended Goals	Anticipated EPA Standards
Coliform Organisms	MPN One per 100 ml	None present	MPN One per 100 ml
PHYSICAL CHARACTERISTICS			
Color Units	15	3	3
Odor, threshold number	3, inoffensive	No odor	2
Residue, mg/l	500	200	
Taste	Inoffensive	None objectionable	
Turbidity, units	5	0.1	1
CHEMICAL CONSTITUENTS	mg/l	mg/l	mg/l
Alky Benzene Sulfonate (ABS)	0.5	0.2	
Aluminum		0.5	
Arsenic	0.9		0.1
Barium	1.0		1.0
Cadmium	0.01		0.01
Carbon Alcohol Extract (CAE)		0.1	
Carbon Chloroform Extract (CCE)	.02	0.04	0.7
Chloride	250		250
Chromium Hexavalent	0.05		0.05
Copper	1.0	0.2	1.0
Cyanide	0.01		0.2
Iron	0.3	0.05	0.3
Lead	0.05		0.05
Manganese	0.05	0.01	0.05
Mercury			0.002
Nitrate	45		
Selenium	0.01		0.01
Silver	0.05		0.05
Sulfate	250		250
Zinc	5	1.0	5
2, 4-D			0.1
Methoxychlor			0.1
Organophosphate Insecticides			0.1 as Parathion (based on organic P)
Endrin			0.0002
Heptachlor			Deleted

TABLE 2

RAW WATER QUALITY IN MERRIMACK RIVER

		Above Lowell			Below Lowell		
		Concentration			Concentration		
		Mean	Max.	Min.	Mean	Max.	Min.
Bacteriological Characteristics							
Total Coliforms		42,127	260,000	3,200	49,824	150,000	13,000
Physical Characteristics							
Color, units		33.75	50.0	25.0	22.87	50.0	4.0
Turbidity, units		5.125	30.0	0.9	2.5	4.0	1.0
Chemical Constituents							
Aldrin	ug/L *	0.0	0.0	0.0			
Arsenic	ug/L	1.40	7.0	0.0	0.0		
Barium	ug/L	14.67	18.0	10.0	-		
Cadmium	ug/L	12.25	30.0	0.0	6.0	-	-
Chromium	ug/L	4.8	11.0	0.0	0.0	-	-
Copper	ug/L	12.17	20.0	0.0	27.5	60.0	10.0
Cyanide	mg/L **	0.0225	0.06	0.0			
DDT	ug/L	0.0	0.0	0.0			
Dieldrin	ug/L	0.0	0.0	0.0			
Endrin	ug/L	0.0	0.0	0.0			
FAS (MBAS)	mg/L	0.05	0.1	0.02	0.06		
Fluoride	mg/L	0.4	0.5	0.3			
Heptachlor	ug/L	0.0	0.0	0.0			
Iron	ug/L	276.7	420.0	200.0	236.8	1000.0	0.34
Lead	ug/L	9.5	13.0	4.0	44.85	124.0	10.0
Manganese	ug/L	59.7	70.0	40.0	95.7	180.0	0.0
Mercury	ug/L	0.6	1.2	0.1	4.7		
Nitrate-N	mg/L	0.511	2.7	0.09	2.81	9.80	0.16
Phenols	ug/L	6.0	14.0	0.0			
Silver	ug/L	0.187	0.30	0.06			
2, 4, 5-T	ug/L	0.0025	0.10	0.0			
Zinc	ug/L	41.8	140.0	0.0	63.3	100.0	0.0
Dissolved Solid	mg/L	77.0	87.0	67.0	63.97	91.0	28.0

* ug/L - micrograms per liter

** mg/L - milligrams per liter

load on the Merrimack River. The effect of various alternative methods of waste effluent management has been discussed in a draft report to the Corps of Engineers entitled "Evaluation of Waste Water Management Alternatives for the Massachusetts Section of the Merrimack River Basin".(27) The following are excerpts from that narrative:

> "The institution of secondary level treatment for the Massachusetts section of the Merrimack River basin will undoubtedly reduce the immediate biochemical oxygen demand (B.O.D.) and suspended solids loading of the affected receiving streams. However, the real and apparent problems of oxygen demanding material resynthesis from available nutrients by primary producers, and the introduction of trace metals and other toxic materials will not be eliminated by this level of treatment. It is apparent from water quality data that it is already a highly nutrient enriched system. When combined with future increased waste inflows, the existing impoundments, and high levels of phytoplankton primary productivity, there is a potential for nuisance algal problems and resultant dissolved oxygen demands.....
>
> "The institution of any of the proposed advanced wastewater treatment alternatives for the Massachusetts section of the Merrimack River basin would have a strong positive environmental impact...... In the Merrimack River it can be expected that advanced wastewater treatment (AWT) will result in increased dissolved oxygen concentrations, reduced turbidity and increased primary productivity.....
>
> "The institution of any advanced wastewater treatment alternative will reduce both the amount of organic material and the toxic materials content of the affected river sediments."

The anticipated effect of implementation of advanced waste treatment would be an improvement in the quality of water in the river. The above report discusses various ways of applying advanced waste treatment techniques. Since each method would likely result in a different level in the quality of the water in the river, we have not presented data on the expected concentrations of chemicals.

Increasing populations in the Merrimack River Valley can be expected to contribute increasing volumes of waste. Passage of these increased volumes of waste to the river without improving or expanding upon present treatment capabilities would deteriorate the quality of water in the river. Implementation of secondary waste treatment is expected to offset the effect of increasing waste volumes, resulting in little change from present water quality characteristics. Advance waste treatment techniques would be necessary to bring about improvement in the aquatic habitat of the Merrimack River.

SECTION III

SITE VISITATIONS

A. GENERAL

During the course of our study visits were made to water treatment plants at Andover, Gloucester, Lowell, and Lawrence, Massachusetts. The purpose of these visits was to determine the efficiency of the various treatment methods being employed by the various communities and to point out areas where improvements in design might be made.

B. ANDOVER, MASSACHUSETTS

Andover has a new facility which went "on-line" during the period of this study.(25) The treatment plant obtains its raw water supply from Haggetts Pond. This supply is augmented by a pumped diversion from Fish Brook. Diverted water is chlorinated as it is pumped to Haggetts Pond. The diversion can also pump water from the Merrimack River. It is intended that only the best quality river water will be diverted, primarily during periods of medium to high run-off. Plant processes include screening, raw water pumping, powdered activated carbon contact, rapid mixing, high energy flocculation, sedimentation and dual media sand and coal filtration.

C. GLOUCESTER, MASSACHUSETTS

Gloucester has two, relatively new - 1971 & 1972 - water treatment plants. Each treatment plant obtains its supply from its own system of surface storage reservoirs. The plants are operated consecutively rather concurrently to utilize the best available quality of raw water and so minimize operational costs and problems. One treatment plant utilizes screening, the other does not. Other treatment processes are similar - rapid mixing, slow mix flocculation, sedimentation, and single media (sand) filtration. The filters are automatically backwashed on a timed, a headloss, or a manual signal.

D. LOWELL, MASSACHUSETTS

Lowell treats water at a water filtration plant placed in operation in 1963.(12) Raw water for treatment is taken from the Merrimack River. The treatment process includes screening, rapid mix, slow mix flocculation, sedimentation, and single media (sand) filtration through automatic backwash filters. Athough the facility has a nominal design capacity of 10.5 mgd, the plant has treated in excess of 14.5 mgd to meet increasing system requirements. After treatment, the water is reportedly plagued by recurring taste and odor problems.

To increase treatment capacity and improve the treatment process, the City of Lowell has begun the planning of plant expansion. (12) The treatment processes proposed for the expanded plant would be similar to the present treatment plant except that the filters would use granular activated carbon as the filtering medium and be increased from the present approximate one foot to about five feet in depth. The granular activated carbon would be used for polishing of the water to remove any remaining tastes and odors in addition to filtering out unsettled particulate matter.

E. LAWRENCE, MASSACHUSETTS

Lawrence also obtains its water supply from the Merrimack River. (27) Water treatment was begun in the late 1800's and improvements and expansions have continued since.

Lawrence reportedly first improved the quality of river water by using an infiltration gallery about 300 feet long built in the bank of the river. Due to clogging of the filter and consequent high labor requirement needed to maintain capacity, the infiltration gallery was abandoned in favor of slow sand filters. After undergoing several modifications, which were the result of investigations conducted in association with the Lawrence Experiment Station of the Massachusetts State Department of Health, the efficiency of treatment by slow sand filtration was judged inadequate due to the lack of pretreatment. Treatment by rapid sand filters, preceded by aeration and sedimentation, was initiated. Although the aeration facilities are kept available, problems with freezing in the winter and intrusion by animals outweigh the improvements in water quality they provide.

The water supplied to the system in the past had a high taste and odor problem. Treatment for the removal of tastes and odors was primarily through the use of powdered activated carbon. Required dosages reportedly were at times over 100 parts per million. In 1971/1972 the sand in the filters was replaced with granular activated carbon. Contact with the carbon reduces the taste and odor content of the finished water as is proposed at Lowell.

A pilot scale ozonator has been installed at the intake raw water pump house at Lawrence. Intermittent use of ozone in the pilot operation indicates that reductions of tastes, odors, color, turbidity and bacterial content can be effected. Insufficient data are presently available to define operating and design parameters.

F. SUMMARY

The Andover and Gloucester facilities indicate trends in the latest technology. Developments have been incorporated into these plants which may have use in the proposed treatment plant. However, these developments are primarily refinements rather than substitutions of unit processes. Therefore, these developements are expected to have little effect on the determination of the unit processes which should be recommended for the proposed facility. These detail considerations are the type of evaluation best made during a pilot plant study.

Operational experiences at the Lowell and Lawrence treatment plants are extremely useful to this study. Since both facilities utilize raw water from the Merrimack River, the facilities can be viewed as full scale pilot plants for the proposed plant, pointing the way to areas which may be eliminated.

Experiences at Lowell and Lawrence indicate that, at times, there is a significant amount of debris in the river water. Both treatment facilities remove much of this debris relatively easily with fixed bar screens and travelling screens.

SECTION IV

UNIT OPERATIONS

A. GENERAL

In preparing our evaluation of the unit processes which are necessary to deliver a high quality drinking water utilizing Merrimack River water as a source, we have considered many processes and operations which have found use in water treatment at other locations. Some of these processes and operations appear to be amenable for serious consideration, others do not appear viable for the objective desired.

Some of the unit processes considered were:

Intakes
Screens
Aeration
Removal of Organics
Coagulation
Chemical Addition
Rapid Mix
Flocculation
Sedimentation
Filtration
Carbon Absorption
Dissolved Solids Removal
Miscellaneous

B. INTAKES

Intakes consist of an opening with a straining device, through which water enters into a conduit to convey the water to a well, pipeline, or sump. Intakes can take many forms, depending on the requirements of the intake and available water supply. (14,36)

Cribs and submerged inlets are used where it is desirable to locate the intake away from shore to obtain better quality water or to assure submergence.

Infiltration galleries are essentially horizontal wells which collect water along their entire length. (41) Such galleries are usually laid in the natural soils near a body of surface water but are sometimes constructed beneath the surface water. Infiltration galleries are subject to the same hazards as shallow wells but have greater exposure to pollution because of their horizontal position.

Channel diversions are structures built at the side of a channel to divert the flow of water from the main stream to an alternate flow pattern. (14,36) The structures may be complex, involving dams, sills and other hydraulic structures or simple channels built at the side of the stream.

C. SCREENS

Screening is an operation whereby particulate matter, either floating or suspended, is "strained" out of the water. (2,14,36) The difference between coarse, fine, and micro-screens is the size of opening. Bar racks are a form of coarse screen.

Coarse screens usually have openings greater than 1 inch. Fine screens may have openings as small as 1/16 inch. Usually the openings in fine screens are on the order of 1/4 to 3/8 inch in size. Microscreens have openings on the order of 20 to 30 microns, although other sizes are available.

Coarse screens, especially bar racks, are usually fixed in place. They are cleaned periodically by raking the debris from the face of the screen.

Fine screens may be fixed or traveling. Fixed screens are usually removed and hosed down by hand to remove debris, whereas traveling screens are removed, hosed and returned by automatic equipment. Cleaning of fine screens is usually done daily unless high concentrations of debris are encountered.

Microscreens are arranged on the periphery of revolving drums. (7) Because of the build up of material on the screen and the attendant increase in head loss, microscreens are continuously cleaned. Design parameters for microscreens dictate large expenditures for construction, operation and maintenance.

D. AERATION

The purpose of aeration is to increase the rate of the establishment of equilibrium of volatile compounds between the water phase and the atmospheric phase. (2,3,14,20,21,36,40) Aeration can increase the level of dissolved oxygen in the water while removing objectionable gases such as carbon dioxide and hydrogen sulfide.

E. REMOVAL OF ORGANICS

In the removal of organics, two methods are commonly employed. Most common is oxidation by means of chemical addition. Also effective, but less common, is adsorption by activated carbons.(13,18,26,40)

Oxidation is a chemical reaction whereby the organics - color, odors, bacteria, etc. - are burned or oxidized, usually to carbon dioxide and water. Some chemicals do not react in the same manner as others. That is, the reactions of some may not be as complete as the reaction of others. Therefore, several chemicals may be provided to permit alternatives and combinations to be employed to achieve an optimum removal.

Activated carbon can adsorb quantities of organics, metals and other minerals onto its surface. These chemicals are stripped from the solution much as a sponge picks up water.

F. COAGULATION

Coagulation is used to allow turbidity and some dissolved substances to be removed from the water by other unit processes.(1,2,3,9,10,33,38) Coagulation occurs when certain chemicals are added to the water. These chemicals precipitate and bond together. In bonding together, or flocculating, the precipitated chemicals pick up turbidity and other materials. As the size of the particle (floc) increases, the floc becomes easier to remove by sedimentation and filtration processes.

G. CHEMICAL ADDITION

While chemical addition is not a unit process in the strictest sense, consideration must be given to provide alternate locations for feeding chemicals. This flexibility affords the treatment plant operator a better control over the treatment process. As previously stated, chemicals often react differently under different conditions. By controlling the conditions at different points in the process, the treatment plant operator can optimize the chemical dosages.

H. RAPID MIX

When coagulating chemicals are added to the water, the reactions with water are virtually instantaneous. In order to assure proper removal of the undesirable constituents at the least dosage rate, it is necessary to have a homogeneous mixture. (2,3,31,40,46)

Homogeneity is achieved with rapid mixers. The purpose of the rapid mixers is to create turbulence as necessary to completely stir the water. Creation of turbulence is usually accomplished by motor driven propeller or turbine blades, although hydraulic mixing in baffled tanks has been used.

Hydraulic mixing has been found by the operators to be adequate at the Lowell water treatment plant, and the electric motor driven propellers removed. Adequate mixing by static hydraulic elements has not been shown to be reliable in plants with varying flow rates - i.e. with varying hydraulic conditions. Thus, rapid mix devices are used to assure adequate dispersion of chemicals under differing sets of conditions.

I. FLOCCULATION

After chemicals are added and dispersed through the raw water, and initial coagulation has occurred, the size of the particles of precipitate are still very small. It is the purpose of flocculation to bond these particles together and include other suspended and dissolved matter. (2,3,13,31,32, 36,38,40) The energy input must be sufficient to drive the small particles together but not so much that large particles are torn apart.

J. SEDIMENTATION

Once the chemical precipitate has been built up to sufficient size, the floc will settle. The purpose of sedimentation tanks is to allow this settleable material to be removed from the water. Sizing, configuration, and methods of sludge removal can greatly influence the efficiency of sedimentation. (2,3,13,31,36)

K. FILTRATION

In sedimentation, settleable particles are removed. However, removal of all particulate matter is incomplete. The purpose of filtration is to remove the remaining matter held in suspension. (1,2,3,4,5,8,12,13,14,18,19,22,25,26, 27, 30,31,35,36,37,38,39,40) This is done by passing the water through a bed of granular material, usually sand or sand and coal.

Particles are removed from the water as it passes through the bed by physical and chemical forces which strain the water and attract the floc to the granular bed material.

L. CARBON ADSORPTION

Activated carbon, as previously discussed, can adsorb materials from water. Among the materials removed by carbon are organics, tastes, odors, and some metals. (12,13,26,27)

The purpose of a carbon adsorption bed would be to provide a final system whereby constituents which were not removed by the more conventional water treatment could be separated from the product water.

M. DISSOLVED SOLIDS REMOVAL

Dissolved solids are picked up by natural water through run off on to water courses. Removal of these solids is sometimes necessary because of their taste and laxative properties. (2,3,31,36)

Removal of dissolved solids can be accomplished by distillation, freezing, reverse osmosis, ion exchange or electro-dialysis procedures. Since these processes are very complex, and usually expensive, the use of any of these processes is usually limited to those supplies which clearly demand treatment. Other uses of dissolved solids removal processes are in the production of ultra-pure water in industries, in boiler make-up water and in the conversion of saline and brackish water for potable use.

N. MISCELLANY

Two processes which are not, directly, part of the treatment of water, but which should be considered in the design of treatment facility, are waste disposal and regeneration of carbon. By far the more important of these is waste disposal. Ultimate disposal of wastes and consumption of non-renewable resources have become problems of environmental consideration. Traditionally, there have been three methods of disposal employed:

1. Direct discharge to a stream or watercourse
2. Lagoons and sludge beds
3. Discharge to a sewage treatment facility

Recent interest in the fields of alum waste reuse has spurred efforts in the development of systems of alum recovery.(15,45) The recovery is performed in three steps:

1. Concentration of the waste sludge
2. Conversion of aluminum hydroxide to aluminum sulfate with sulfuric acid
3. Removal of impurities by filtration.

Not all the alum is recovered but the efficiency of recovery should be sufficient to more than offset the cost of the operation.

Since some waste remains from the recovery process, a method of disposal for this waste must be found. The volume however is greatly reduced and land disposal, for even the larger plants, seems a likely procedure.

Activated carbon has a finite adsorption life. Periodic replacement with new active carbon is necessary to assure required removals. On-site reactivation of granular activated carbon can be justified for larger (above 30 mgd) facilities. The regeneration would be accomplished by treating the spent carbon in a multiple hearth furnace.

Ancillary facilities such as shops, offices, lunch rooms, laboratories, and garages must also be provided in order that the treatment works function properly. In addition, landscaping should be provided to enhance the physical aspect of the facility, making the plant more acceptable as an addition to the community.

SECTION V

SELECTED UNIT PROCESSES

A. GENERAL

The unit processes selected for inclusion in the proposed water treatment plant were the combination of processes which are expected to produce a high quality finished water at the least overall cost. Reliability and flexibility, in addition to low costs, have been factors which have been taken into consideration when comparing unit processes.

Those processes and facilities selected were:

- Channel diversion - Intake
- Coarse and fine screens
- Chemical coagulation
- Rapid Mix
- Flocculation
- Sedimentation
- Filtration
- Carbon Adsorption and Regeneration
- Waste Treatment
- Ancillary Facilities

The treatment functions are shown on the Process Flow Diagram, Figure 1.

Discussions with plant personnel and observations of operation at the water treatment facilities at Lowell and Lawrence, Massachusetts exhibited important influences on the decisions regarding processes to be included in the proposed water treatment plants. These existing facilities have served to some extent as full scale pilot plants for this report. From their operating experiences, certain guides can be established with regard to design parameters. These parameters should be investigated by pilot plant studies. The purpose of such studies would be to establish finite design parameters and confirm operating efficiencies.

B. INTAKE

As used in this evaluation, the intake would be similar to the intakes at Lowell and Lawrence and would be a combined structure housing a raw water pumping station in addition to providing hydraulic access to the river. Since the river is comparatively shallow (10 to 20 feet), water would be taken throughout the full depth.

Bar Screens at the edge of the stream would remove the largest particulate matter from the incoming water. Travelling screens located within the intake structure would remove finer particles (on the order of 1/4 to 3/8 inch size). Material collected by the screens could be returned to the river or removed to a waste disposal area - either incineration or landfill.

Water passing through the screens would enter a sump. From the sump the water would be lifted by raw water pumps to the remainder of the treatment plant. Equipment on the pump discharges would monitor and control the output of the raw water pumps. The capacity of the pumps, intake and piping have been taken as 125% of the nominal design capacity.

C. CHEMICAL ADDITION

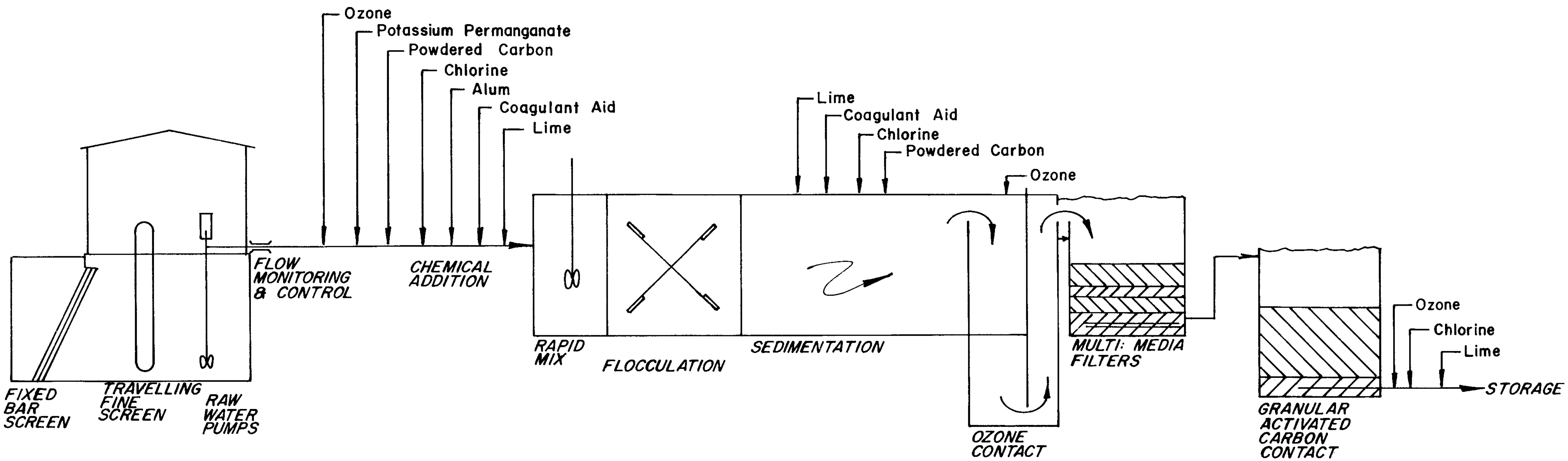
As indicated on Figure 1, chemicals may be introduced to the water at several points during the treatment process. This will allow chemicals to be added at the point where their effect will be optimized.

Since the chemicals perform many functions, a variety of compounds have been included in the design. The chemicals considered being used in the treatment process are:

- Alum
- Lime
- Chlorine
- Ozone
- Potassium Permanganate
- Coagulant Aid

Caustic soda and powdered activated carbon could also be used.

Caustic soda was not recommended due to its current cost and limited availability compared to lime. Lime is more difficult to handle but in the size treatment plants discussed herein, the added handling cost of lime should not be significant. Therefore, lime was used as the most economical method of providing the alkalinity required for coagulation and for pH adjustment.



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MERRIMACK RIVER
TREATMENT PLANT STUDY

PROCESS FLOW DIAGRAM
FIGURE 1

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Powdered activated carbon is proposed to be replaced by the oxidation reactions of ozone and the adsorption capacity of activated carbon contact in granular carbon filter beds. However, provision has been made in the layout of the chemical storage and feed facilities for future incorporation of powdered activated carbon and caustic soda, should it be decided at a later date to use these chemicals.

Alum was chosen for this evaluation as the primary coagulant. Alum has been the coagulant of choice in most water treatment plants and little change in the final results would be effected by the choice of a different primary coagulant such as ferrous sulfate or ferric chloride. The efficacy of primary coagulants should be made part of any pilot plant study.

Chlorine was used as the primary disinfectant. We have assumed that chlorine gas would be the form of chlorine used. Analysis of the use of either commercially available or on-site generated hypochlorites is beyond the scope of this study but should be considered in final design. While each form of chlorine has advantages and disadvantages, it is felt that there would be relatively little variation in estimated construction costs or in operation and maintenance costs.

Ozone will be used as an oxidant for the removal of tastes, odors, colors, some soluble metals, breaking down exotic hydrocarbons and for the deactivation of viruses.

Ozone, O3, is an unstable form of oxygen having a pungent odor. Ozone is formed in the corona discharge of high voltage electricity in pure oxygen or dry air. For large installations, dry air is usually used.

Ozone is corrosive (due to its high oxidative capacity) and poisonous in high concentrations. In the presence of oxidizable materials in water, residuals rapidly disappear. Most organisms are inactivated if an ozone residual can be detected.

Ozone, due to its instability, would be generated as required. Ozone could be used in lieu of chlorine for much of the disinfection of raw water. In addition, the greater oxidizing power of ozone, as ompared to chlorine, would more efficiently reduce the numbers of viruses and the levels of exotic hydrocarbon compounds. Use of ozone should extend the useful life of the carbon contact beds.

Potassium permanganate will be used as an oxidant to remove tastes, odors, colors and to remove soluble iron and manganese. Potassium permanganate would be used only during those periods of the year when other, less expensive, oxidants were found to be ineffective.

Coagulant aids would be used to reduce the expense of coagulation by decreasing the required dosages of alum and lime. Coagulant aids might also be used to improve settleability and filterability.

D. RAPID MIX, FLOCCULATION AND SEDIMENTATION

Rapid mixing, flocculation, and sedimentation are relatively straight-forward unit operations. Sizing of units is based on detention times, flow rates and power requirements.

Provision should be made to permit varying the mixing rates of the rapid mix and flocculation mechanisms. Provision must be made for removal of settled sludge from the sedimentation tanks. The proposed design includes mechanical sludge collection equipment.

The proposed design also includes covering the rapid mix, flocculation and sedimentation tanks. Use of a cover prevents external contamination and eliminates wind induced currents which can stir up sediments and also minimizes heat transfer from or to the water.

E. FILTRATION

In order to minimize the size of filters and hence reduce the cost of the filter installation, we recommend the use of multimedia filters. This type of media will permit a higher rate of flow to be applied to a given surface area than other types of media. The reduction in filter size would more than offset the higher cost of the media. Controls would be provided to monitor and limit filter effluent flow rate, turbidity, loss of head, surface washing, and filter backwashing.

F. GRANULAR CARBON CONTACT

After the raw water has been treated by the traditional processes discussed above, we recommend that the water be given a final treatment by granular carbon contact.

Experiences at Lowell and Lawrence indicate that traditional treatment may not be sufficient or is difficult to apply to obtain the highest quality effluent. Lawrence has installed activated carbon in their sand filters and Lowell proposes to install granular carbon filters during its next plant expansion.

Although granular carbon can act as a filter to remove particulate matter, differences in design parameters make this method of construction more costly for large facilities and only slightly less costly for smaller facilities. Further, the cost of replacing spent carbon is one of the prime reasons activated carbon has not been more widely used. In order to extend the active life of the carbon, as well as provide better control of removals, the carbon contact beds have been separated from the filters. Since activated carbon has a finite capacity to adsorb material, it will be necessary to monitor the product water to determine when the carbon needs regeneration.

G. ADDITIONAL FACILITIES

Although the foregoing items are those processes which will treat the water to produce a high quality effluent, they are by no means the only portions of the design of a treatment plant which must receive consideration. As previously discussed, a treatment plant must have facilities for a laboratory, administration, repair of equipment, storage and receiving of chemicals, pumping facilities to deliver the treated water to the distribution system, garages, waste treatment, and, for this plant, a carbon regeneration installation.

The facilities for laboratory, administration, repair, and garaging are dependent, to varying degrees, upon requirements beyond that of the treatment plant proper. Also, since the variables of plant capacity and water quality have less effect on the cost of these facilities, the estimates of cost, have been taken as a percentage of the total construction cost. Pumping to the distribution system, we understand, is part of a separate analysis dealing with the transmission of the treated water.

Chemical storage, waste treatment, and carbon regeneration facilities are directly related to the size of plant and the unit processes included therein.

Chemical storage and feeding are important adjuncts to the treatment process. Storage is necessary to allow a sufficient lead time to be able to place and receive an order for a particular chemical. Chemical feeders must be capable of delivering an accurate dosage of chemical and must be able to adjust or be adjusted for varying flows and varying water qualities.

An alum recycling plant is recommended for treatment of wastes. Efficiency of recovery of existing full size plants in Japan is in the order of 50 to 70 percent. (45) Pilot operations in the U.S. have somewhat better recoveries. (15,45). Efficiency is apparently attributed to process design and control parameters.

Solids are removed from the recycled alum while the build-up of soluble impurities may require periodic or continuous blow down. Thus, some wastage is to be expected. A method of disposal must be found for these materials. Often this waste material can be put into a sanitary sewer without further treatment or after pH adjustment. Since there is little or no biological waste involved, the alum flocculating ability of the waste material can increase the solids removal efficiency of primary settling tanks at the sewage treatment plant. Another potential disposal method is to a landfill. This method does call for pH adjustment to prevent acid contamination of the soil.

Carbon regeneration by on-site facilities would reduce the operations cost of carbon replacement. The savings in operating cost is estimated to be greater than the capital investment cost for all but the smaller plants (below about 30 mgd). Therefore inclusion of a carbon regeneration facility can be justified for larger plants.

H. SUMMARY

Each of the proposed unit processes is intended to serve a specific function. However, rather than considering each process as an individual entity, the total treatment process should be considered as a single operation, the purpose of a treatment facility being to produce as high a quality water as possible at the least effort.

In the past, a high quality water was a water that looked and tasted good and gave off no objectionable odor. As the level of knowledge increased, the expectation of a high quality water included bacterial and chemical qualities. With present technology capabilities, the public should expect that its water be free of potential dangers from viruses, heavy metals and organic chemicals in addition to the water containing no bacteria or unwanted tastes and odors. The proposed facilities will accomplish the desired treatment by modifying, removing, polishing and oxidizing the contaminants in the raw water.

Organic matter, including tastes, odors and colors, will essentially be removed by the conventional treatment processes of flocculation, sedimentation, and filtration. Flexibility of treatment using the different chemicals which can be employed and the alternate feed points provided will permit high treatment capabilities under varying river water characteristics. Removal efficiencies can be expected to approach 100%. (3,12,13,14,18,26,27,31,40) Any organics which escape removal by flocculation, sedimentation and filtration would be removed by adsorption in the activated carbon contact beds, or, escaping the carbon beds, be oxidized by final ozonation and chlorination.

It has been shown in the past that viruses may not be completely removed from water by traditional treatment procedures of flocculation, sedimentation and filtration. Viral and bacterial removals by the coagulation-filtration process have been on the order of 98 percent. (13) Application of ozone has been more effective than chlorination in the inactivation of viruses and in the germicidal effects on bacteria. (3,7,13,16,17,18,24,34,44) Viruses have been inactivated by ozone, in residual concentrations of 0.05 to 0.45 parts per million, within two minutes. (13)

Application of present technology will insure removal of organic and particulate matter from the water and, when followed by a disinfecting agent, will guarantee complete virus removal. Removal of the organics reduces the demand for the disinfecting agent while removal of the particulate matter eliminates a potential shield whereby viruses may be protected from attack by the disinfecting agent. The filters, carbon contact beds, and final ozonation and chlorination are intended to insure maximum reliability of performance.

Heavy metal removal from water supplies is not a common occurrence. (29) In the past, where a potential source of supply has shown high concentrations of certain minerals, alternate sources have been developed. Generally, these have been small supplies. (29) With larger supplies, it is rarely possible to develop an alternate source. With increasing mineral concentrations in supply sources and application of more stringent criteria for evaluation, treatment facilities must be capable of removing these constituents.

Experiments using the unit processes recommended for inclusion in the proposed treatment facility have demonstrated heavy metal removal. (10, 13, 29) In one instance, ninety-five percent of cadmium was recovered by the use of the polyelectrolyte. (10) In other analyses, heavy metals have been shown to be removed from water by coagulation with polyelectrolytes and alum. (10,13,29)

Carbon adsorption has also been used to remove heavy metals. (13,29) This process is most effective when organics are also removed from the water along with the heavy metals.

Analysis for heavy metals of the water treated at the Lawrence and Lowell water treatment plants has not been made on a regular basis in the past. A study, sponsored by the EPA, is now under way nationwide to determine concentrations of chemicals, including heavy metals, in treatment plant effluents. The study will also determine changes in organic compounds caused by chlorination. The results of the study should give an indication of the efficiencies which can be expected from water treatment processes.

The pilot plant investigations recommended in this report should utilize the results of the EPA study and should analyze trace constituent removal by the various processes as part of the investigations. Although metals can most easily be controlled at the source of contamination, the unit processes recommended to be used will prevent the concentration of a heavy metal in the product water from exceeding the prescribed limits. The processes proposed to be included in the treatment facility will function together to supplement and amplify each other. The total effect will be the capability of treating the raw water to provide a high quality supply.

SECTION VI

UNIT PROCESSES NOT INCLUDED IN PROPOSED TREATMENT PLANT

A. GENERAL

During the course of this study, many processes were considered and investigated. Some of these processes could be readily eliminated from further review because their purpose was not applicable to the type of raw water being treated. Other processes were eliminated because the cost analyses indicated that other, more economical, methods of treatment were available which would accomplish the same objective. Many of the conclusions reached by this investigation have been confirmed by processes used and abandoned or modified by the treatment facilities at Lawrence and Lowell.

B. INTAKES

Submerged cribs and infiltration galleries were eliminated from proposed design for economic reasons. Since the river is reportedly comparatively uniform throughout its width, both in cross-section and in water quality, the use of a submerged crib was negated. The high degree of subaqueous work required to build the structure and the need for underwater maintenance and protection made this alternative an expensive proposition when compared to the channel diversion recommended. Use of a submerged crib would not eliminate the need for screening devices, so the only differential in cost would be in the excavation and concrete work.

An infiltration gallery would eliminate the need for screens. The land requirement would, however, be large and experiences at Lawrence point out the high maintenance required to keep the gallery operational.

C. Microscreens were considered as a means of controlling the amount of small particulate matter, principally algae, which would be carried into the sedimentation basins. The cost of using microscreens would have to be offset by a savings in chemical treatment. Review of the present operations at Lowell and Lawrence does not indicate that removal of particulates would be significantly beneficial. The major areas where savings in operating cost could be effected at Lowell and Lawrence are in removal of dissolved taste and odor causing substances. Since microstrainers are costly to install and to operate, no further analyses was performed.

D. AERATION

The purpose of aeration is gas transfer, either to or from the water. Aeration is not usually applied to surface waters since there is little dissolved gases in the raw water. This is the indicated condition of Merrimack River water.

Reported experience at Lawrence indicates that aeration is not a necessary process for treating the raw water. The aeration facilities were taken out of service because of land requirements for expansion, intrusion by animals, and the degree of treatment provided by aeration did not justify the expense of operation and construction.

E. CHEMICALS

Many chemicals are employed by treatment plants to accomplish various end results. The proposed treatment plant includes only a limited number of these chemicals. Among those chemicals not included are chlorine dioxide, powdered activated carbon, and various primary coagulants.

Chlorine dioxide was not included because the difficulty in preparing the solution and the fact that the chemicals proposed to be used would furnish the equivalent oxidative capacity needed. The added capacity from the sue of chlorine dioxide would be unnecessary.

Powdered activated carbon should not be required because of the carbon contact beds recommended and the other treatment the raw water is proposed to receive. Powdered activated carbon has become a powerful ally of the treatment plant operator. Therefore, although no cost has been included in the cost of operation and maintenance, we have provided in the cost analyses for powdered activated carbon storage and feeding.

Primary coagulants, other than the magnesium cargonate-lime process, should not have process design, operational or maintenance parameters very different from those same parameters for alum. Since alum has been the primary coagulant of choice in most water treatment plants, and we find no significant reason to change, other primary coagulants were not investigated.

The magnesium carbonate-lime process is somewhat different from the alum process requiring separate operations to remove magnesium and lime. This process is particularly useful where the hardness and alkalinity are high. Merrimack River water, as is typical of most water of New England, is relatively soft and slightly acid. Therefore, no consideration for the costs of magnesium carbonate-lime coagulation was undertaken.

F. FILTRATION

Of the many arrangements of filters, we have recommended the use of multimedia filters because of the high surface loading capability of that type of filter and the economy to be gained by reducing the size and number of filters. Another type of filter, a dual media, or sand-coal filter was investigated. When coal is used as a filtering material in combination with sand, the coal rests on top of the sand. The result is an increased volume for storage of material filtered from the water passing through the filter. This allows longer filter runs between backwashing or faster filtering rates.

Two additional filter arrangements were investigated. The dual media filter would be followed by granular activated carbon contact beds in one case, and in the second case the granular activated carbon would be substituted for the coal in the sand filter.

In the first case, higher filtration rates are permissible through the dual media filter. However, there is the added cost of granular carbon contact beds.

Substituting granular activated carbon for the coal in the dual media eliminates the need for a second contact bed. The filtering rate is reduced because of the contact time required for the activated carbon. Also, the quality of water in contact with the carbon is not as high as when contact follows filtration.

The resultant of these design considerations is an increased cost of filtering facilities. Because of this higher over-all cost, these filters were not recommended.

Direct filtration or, filtration without sedimentation, has been used by several authorities as an economical process. (1,19,35,37,39) By using direct filtration the sedimentation tanks are eliminated. This means that all solids to be removed from the water must be stored in the filter. Where direct filtration has been successful, the raw water has high clarity so that little solids need be removed. Where clarity has deteriorated, the length of filter run has been severely reduced and the volume of water wasted through backwashing has been large. (18) Since the solids to be removed from Merrimack River water by treatment are significant, this method of treatment was not further pursued.

G. DISSOLVED SOLIDS REMOVAL

Results of periodic sampling and analyses of Merrimack River water (See Appendix A) indicate the mineral content to be within the limits proposed by the U.S. Environmental Protection Agency. The treatment processes proposed to be included in the treatment facilities will reduce the concentrations of nearly all of the heavy metals present in the raw water. This is substantiated by experiences at other operations. Therefore, there appears to be little justification for using dissolved solids removal processes since they are costly to install and operate as compared to the results to be achieved.

H. WASTE DISPOSAL

As discussed in Chapter XII, Unit Operations, the ultimate disposal of water treatment plant wastes has become an item of increasing concern. Direct discharge will no longer be permitted under the rules promulgated by the EPA. Discharge to a sewage treatment plant does not seem a likely possibility due to the lack of operating treatment plants in the Lowell-Lawrence area. Further, discharge of waste to a sewage treatment plant permits no recovery of chemicals.

Lagoons have been used as a means of disposal at many locations. These are not an ultimate means of disposal, however, since lagoons would have a finite capacity. Further, we estimate the cost of lagoons for treatment plants with a capacity greater than 100 mgd would be more than the construction cost estimated for the recommended alum recovery plant. Therefore, since lagoons are not an ultimate disposal method, nor provide a means for reducing operating costs through recovery of chemicals, lagoons are not recommended.

SECTION VII

COST ESTIMATES

A. GENERAL

Cost data presented herein for water treatment unit processes and ancillary facilities are based on a review of available 1973-74 construction costs for comparable projects as well as other supplementary and substantiating cost data.

Each of the proposed unit processes were analyzed individually for construction cost, annual operational cost, and annual maintenance cost. Cost estimates were prepared for several plant capacities covering the range of 10 mgd to 500 mgd. Basic layouts of each unit for each capacity were prepared, quantity take-offs were made and unit costs assigned to each item. Where possible, quotations on the value of equipment were obtained from manufacturers' representatives.

All costs were advanced to an Engineering News Record Construction Cost Index (ENRCCI) of 2000. The ENRCCI for June 1974, for Boston was 2034, and the twenty cities average was 1994. An Index of 2000 would be applicable to the Merrimack Valley in mid 1974.

Graphs indicating the estimated costs for construction, annual operation and annual maintenance for the recommended unit processes for complete treatment facilities are presented on Figures 2, 3 and 4. Detail calculations and tabulations for the various individual processes and components are presented in Appendix B. Graphs of the various individual costs are presented in Appendix C. Since the estimates of cost prepared for this report are approximations, it has been necessary to round off the results of the various computations. At best, an estimate is a close approximation of the actual cost. The true value of the work will not be known until the project is completed and all costs are tabulated. Presentation of results, more detailed than the numbers shown, would imply a greater accuracy in estimating than is actually the case.

B. CONSTRUCTION COST

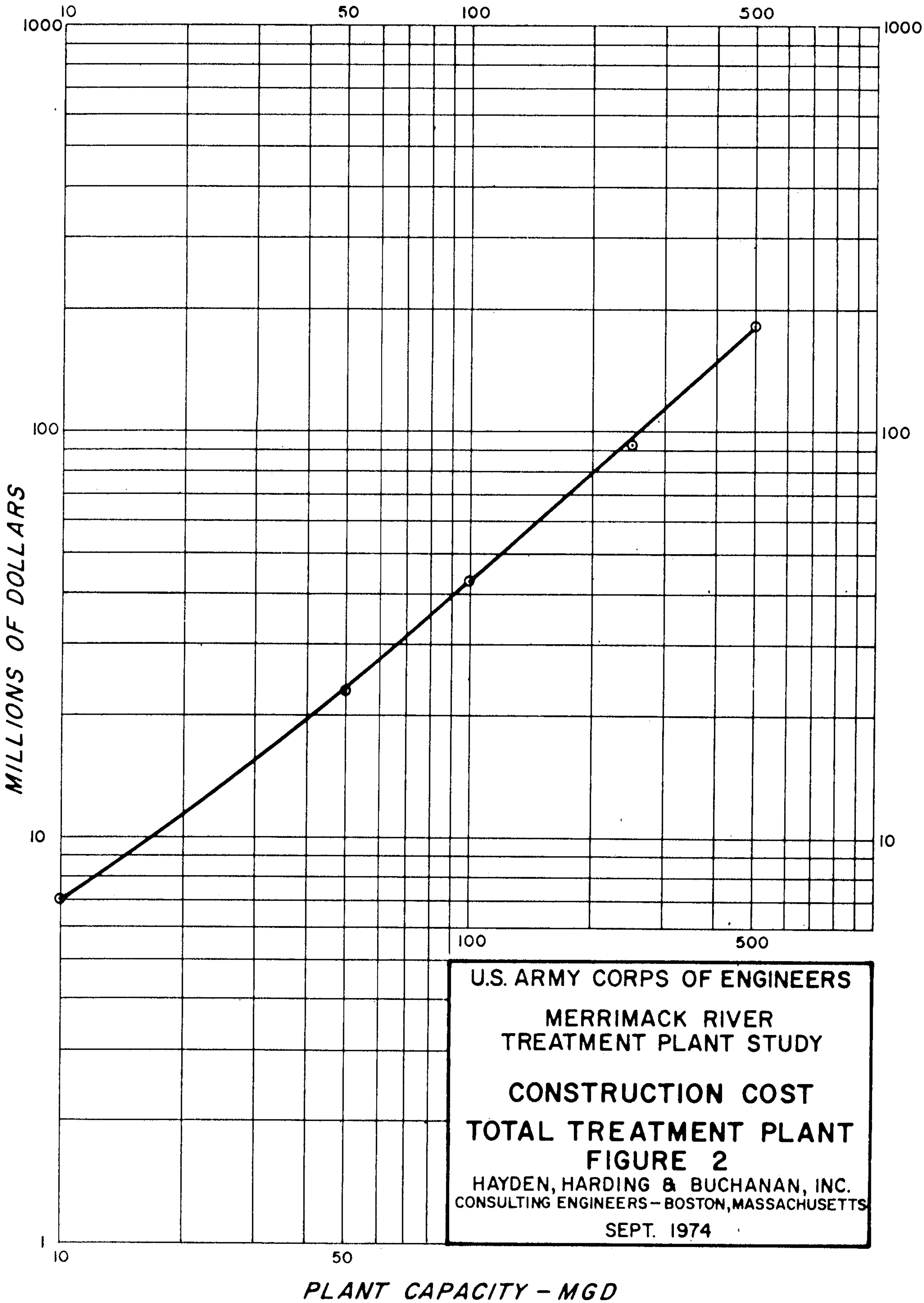
In order to determine the construction cost of the various unit processes, it was necessary to prepare basic

TABLE 3

BASIC DESIGN CRITERIA

Intakes	2 feet per second maximum flow rate through screens when blockage by debris is considered.
Raw Water Pumps	125% of nominal capacity plus 1 spare pump.
Rapid Mixing	Detention Time - 60 seconds
Flocculation	Detention Time - 30 minutes
Sedimentation	Detention Time - 4 hours Surface Loading - 500 gallons per day per sq. ft. Sludge Removal - Mechanical
Ozone Contact	Detention Time - 5 min. Depth - 16 to 18 ft.
Filtration	Multimedia Surface Loading 5 gallons per min. per sq. ft. Maximum headloss - 8 ft. Appurtenances - Flow control, Surface wash, Turbidity monitoring
Carbon Contact	Unit loading - 1 gallon per min. per cu. foot. Depth of Carbon - 5 ft. Surface Loading - 5 gallons per min. per sq. ft. Maximum Headloss - 4 ft. Appurtenances - Flow control, Surface wash, Turbidity monitoring
Chemicals	Duplicate feeders, each at 200% of nominal capacity.

Chemical	Nominal Dose - ppm
Alum	20
Lime	10
Potassium Permanganate	3
Chlorine	5
Powdered Carbon	5
Coagulant Aid	1
Ozone (provide only 100% capacity)	3



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MERRIMACK RIVER
TREATMENT PLANT STUDY

CONSTRUCTION COST

TOTAL TREATMENT PLANT

FIGURE 2

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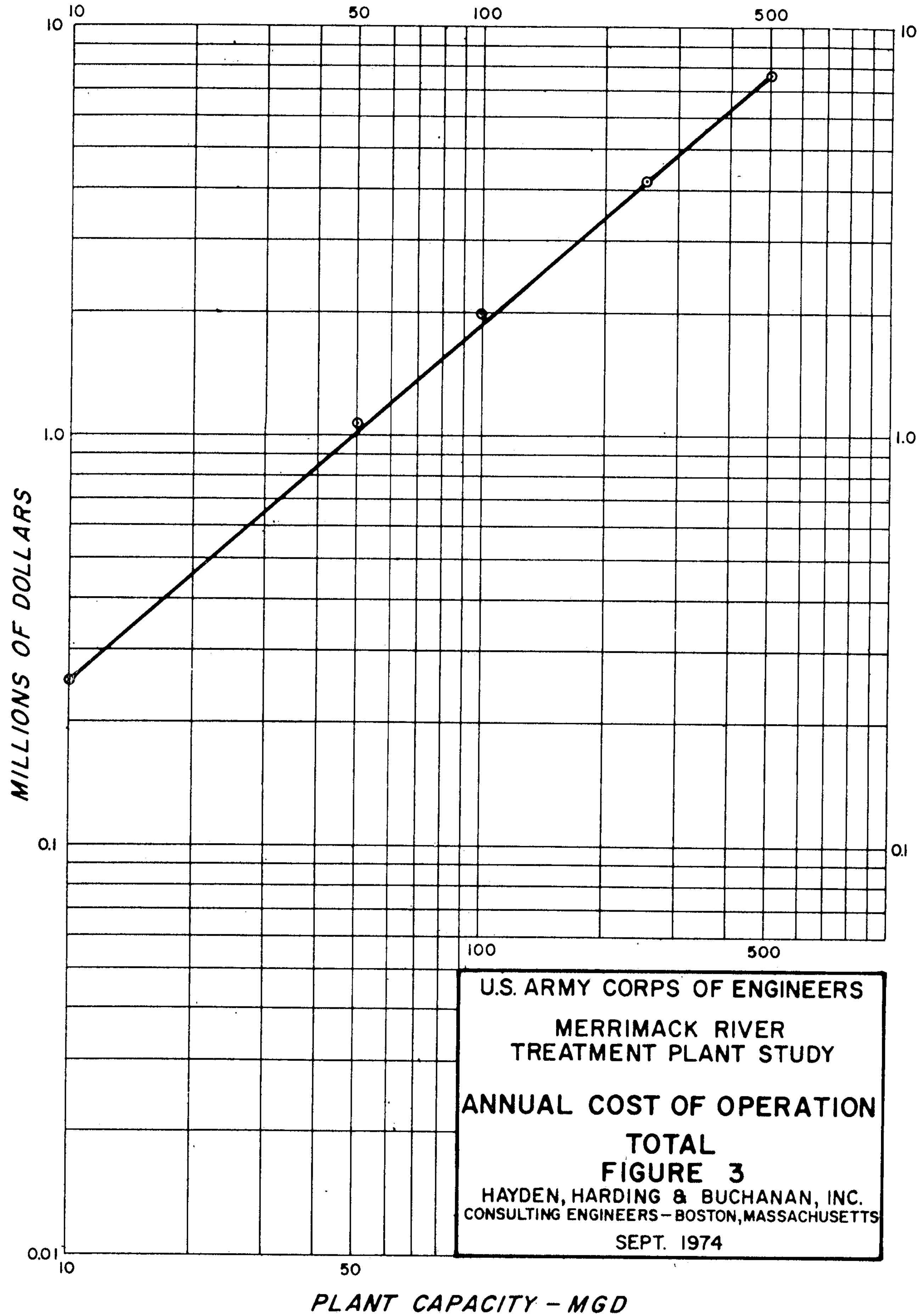

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MERRIMACK RIVER
TREATMENT PLANT STUDY

ANNUAL COST OF OPERATION
TOTAL
FIGURE 3

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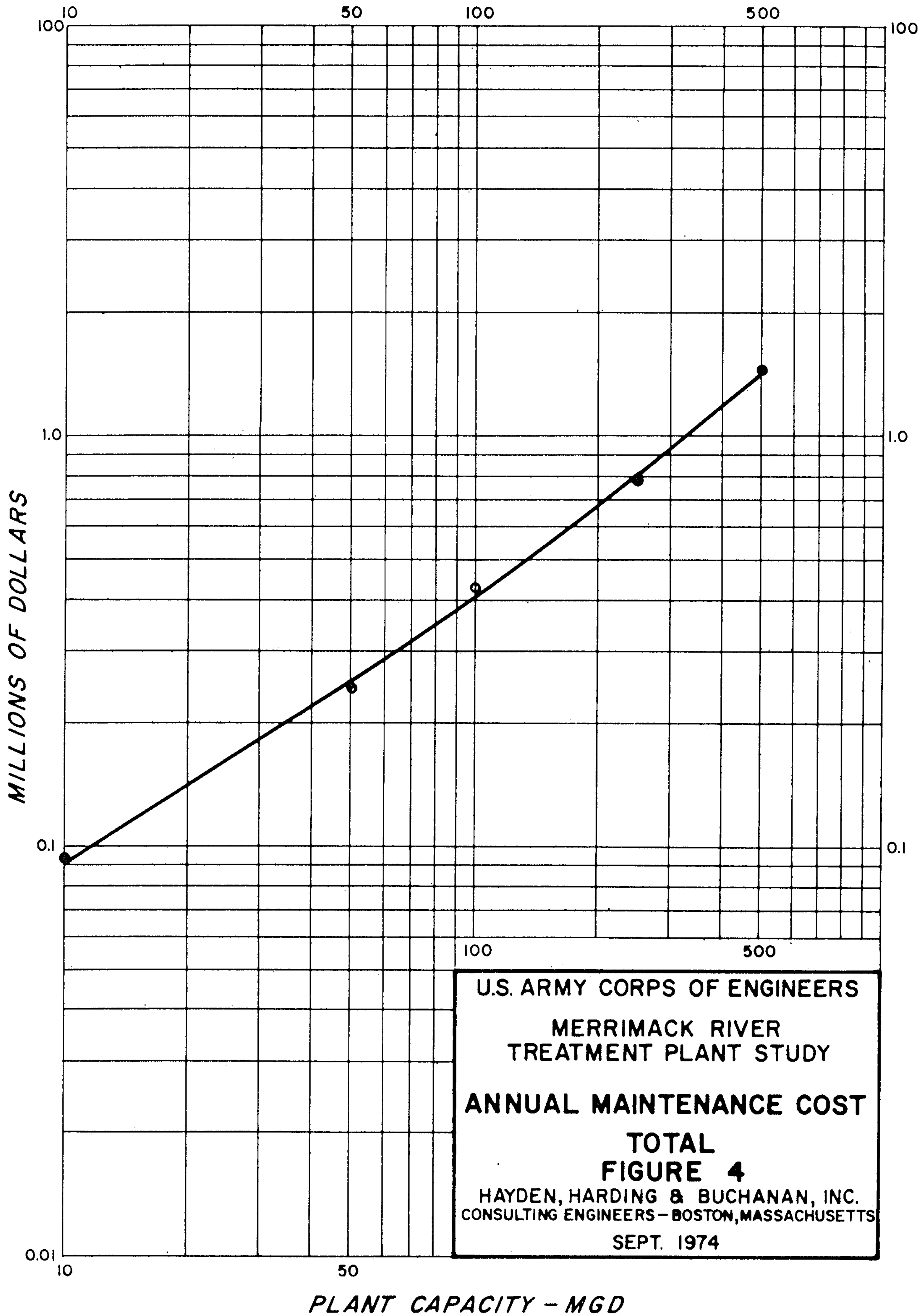


10
50
100
500
100
1.0
0.1
0.01
MILLIONS OF DOLLARS
PLANT CAPACITY – MGD
U.S. ARMY CORPS OF ENGINEERS
MERRIMACK RIVER
TREATMENT PLANT STUDY
ANNUAL MAINTENANCE COST
TOTAL
FIGURE 4
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS – BOSTON, MASSACHUSETTS
SEPT. 1974

Using these criteria, rough layouts were made to determine potential arrangements of processes. Each process installation was sized for each of the plant capacities investigated.

From the rough layouts and sizing, it was possible to determine the major portions of construction work needed to make a complete installation. These were assigned unit prices, extended and totaled. The unit prices were determined so as to include incidental appurtenances and design contingencies.

C. OPERATING COSTS

In the development of cost curves for the operation of the water treatment plant, the average horsepower usage of each of the processes was determined. For the purpose of this study, the raw water pumps were assumed to have a dynamic lift of 30 ft. For the purpose of determining average power costs, high lift distribution pumps, having a lift of 300 ft., were included in the estimated power requirements. The total power consumption of each capacity treatment plant was then estimated and total monthly electricity costs determined using the latest available (Jan. 1974) Massachusetts Electric Company electric rate (optional large-power rate H). From these costs, the average annual cost per horsepower was calculated. Each unit process could then be assigned its proper cost for power.

Separate costs were determined for treatment chemicals and for labor. Neither of these items was broken down nor allocated to a particular unit process but are presented as separate information.

Alum recovery plant operational costs include chemicals needed for recovery operations and disposal of waste sludge in addition to the cost of power. No allowance has been made to the operating cost of the alum recovery plant for the value of recovered alum. However, the use of recovered alum has been assumed in connection with the estimated cost for treatment chemicals.

Other operating expenses were deemed to be of an incidental nature or were included as a maintenance cost. Energy for winter heat and summer cooling was assumed to be at the same rate as electric power and was taken as part of other miscellaneous demands.

D. MAINTENANCE COSTS

In order to develop estimates of the cost of maintenance of the various processes, each process was separated into component parts. Each of these parts was analyzed for its contribution to the need for maintenance.

Each part was then assigned a factor for an estimate of the value of maintenance. This factor is based on repairs, lubricants, periodic replacement, painting, overhauling, and other like procedures.

The regeneration or replacement of granular activated carbon in the carbon contact beds was taken as maintenance cost rather than an operating cost. Costs of carbon regeneration include fuel and power. Replacement of carbon lost through attrition and burning during regeneration was taken as 10% of the amount of carbon regenerated.

Upkeep of the grounds and buildings were also taken as maintenance rather than operating costs. These items are expenses for work which maintains the status quo of the facility rather than being a function of the treatment of the water.

E. ITEMS NOT INCLUDED IN ESTIMATES

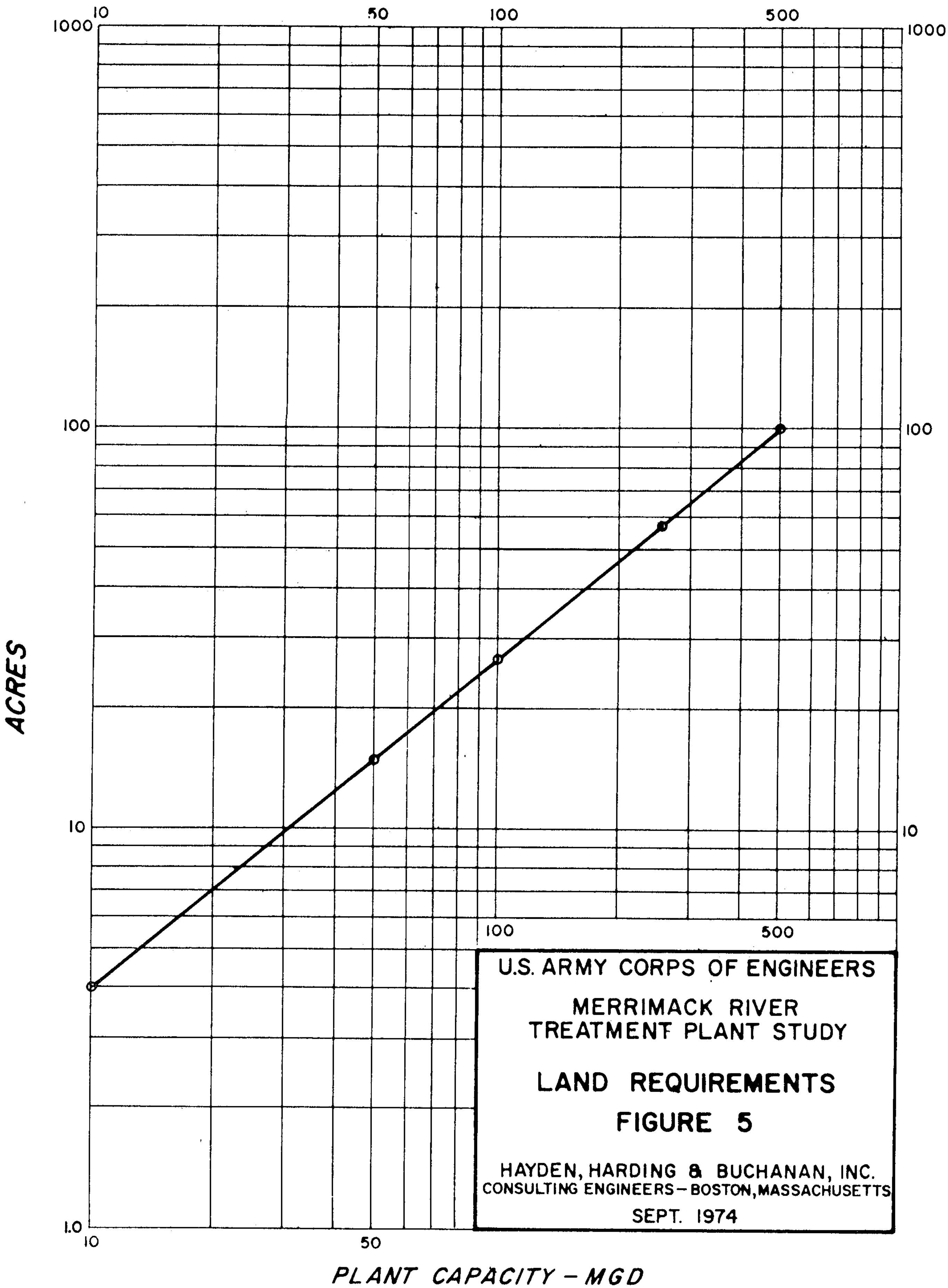
Certain items, which would be part of any civil project, have not been included in the estimates of cost prepared for this report. These items are project costs which are not attributable to any particular function of the project but are expenses which would be incurred and should be included when considering total project costs. Some of these items are considerably variable in nature so that it would be misleading to make an estimate of cost until more definitive data are available.

The items of cost which have not been included in cost estimates are such items as:

1. Land purchases
2. Engineering Fees for Contract preparation and Inspection of construction
3. Legal and Financial Fees
4. Interest and Bonding Costs
5. Construction Administration
6. Design Contingencies

The value of the above items with the exception of the cost of land, is often taken as a percentage of the construction cost. However, the percentage so taken would be dependent upon the particular agency which would have the proposed facility constructed.

Although we have not made an estimate as to the cost of land, it would be useful to have an estimate as to the amount of land necessary for a given water treatment facility. In order to fulfill this need, we have prepared the graph shown on Figure 5. The treatment plants used to determine cost data were used to determine land requirements. In each case allowances were made for expansion and for buffer zones and landscaping. The land requirement shown is only an approximation of what a specific plant at a specific location might require.



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MERRIMACK RIVER
TREATMENT PLANT STUDY

LAND REQUIREMENTS

FIGURE 5

HAYDEN, HARDING & BUCHANAN, INC.
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SECTION VIII

EFFECT OF ASSUMPTIONS

A. GENERAL

During the preparation of this report it has been necessary to make many assumptions involving construction methods, operating capabilities and plant arrangements. These assumptions have been based on past experience, current available information and on the best engineering judgement.

Revisions in some of the assumptions could significantly affect the estimates of cost. Revisions of other assumptions would have very little effect on cost estimates. One of the primary purposes of establishing the design criteria at the values chosen is to minimize the monetary effect of changes in final treatment design requirements.

B. CONSTRUCTION COSTS

Several factors can act to change the estimates of construction costs. The most influential factor is the type of foundation soils present at the site of construction. The presence of large quantities of unsuitable material such as rock or peat could increase costs immensely.

Accessibility can be another significant factor. The proximity of the chosen site to the raw water supply, electric power lines, railroads, and highways would have a direct bearing on the cost of providing these supporting services.

Changes in construction procedures and the future availability of materials of construction or treatment chemicals might dictate a revision of design criteria. Advancements in water treatment research may indicate a revised treatment method which could change the esign criteria or even the total treatment process. Such changes would dictate adjustments in the construction cost.

Changes in raw water quality should have only minor effects on the estimated construction costs of the proposed treatment processes. The treatment capabilities of the proposed processes are sufficiently adaptable to permit the treatment of raw water having widely varying quality and still consistently produce potable water meeting established standards. If, however, the raw water quality were to deteriorate significantly, as with increased untreated sewage discharges, then additional treatment processes might be required. The construction cost of such additional processes would than have to be added to the present estimates.

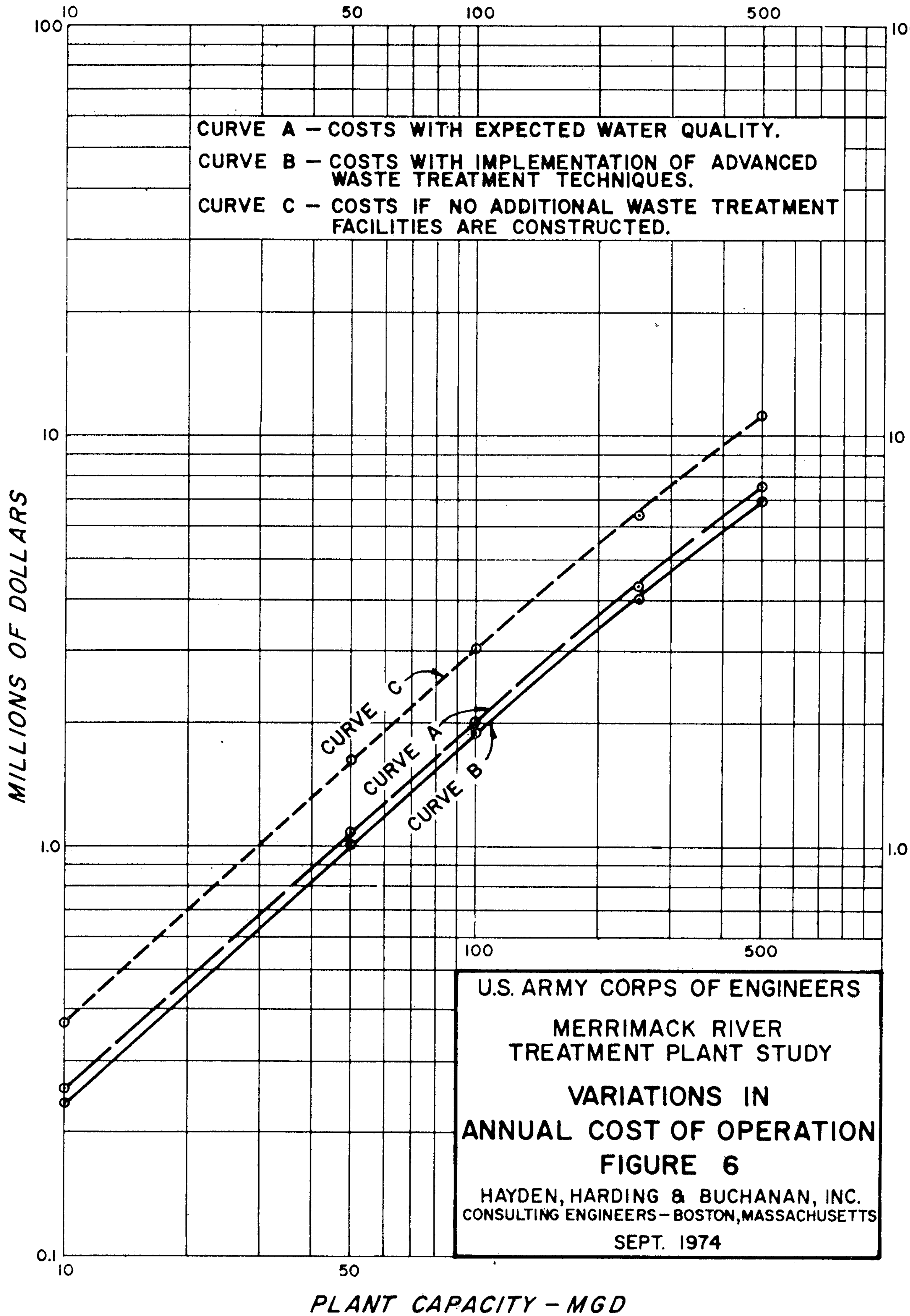
C. OPERATING COSTS

The two most important factors which affect the annual operating costs are the quantity and the quality of the water treated. For the purpose of determining annual operating costs, we have assumed that the volume of water treated will be constant and equal to the design capacity of the plant. It is recognized that variations in demand occur (i.e. higher in summer, lower in winter). So long as these variations are not large and annual production approximates the assumed quantities, as with usual treatment plant operation, the estimates of annual costs should be valid. The anticipated annual costs of operation, as discussed in Section VII, are indicated by Curve A of Figure 6, Variations in Annual Cost of Operations.

Certain of the factors which make up the total annual cost of operation which should be primarily affected by plant capacity are labor, power, and ozone. These items should remain constant under any given set of conditions regardless of water quality.

Since the volume of water treated will be relatively constant for any particular capacity plant, the quality of water taken from the river will be the more significant factor in determining annual operating and maintenance costs. With the application of advanced waste treatment techniques to waste discharges, the quality of river water is expected to improve. This improvement is expected to be most noticeable in the levels of bacteria and turbidity. The raw water would, therefore, be easier to treat since less material must be removed.

It would appear that ozone dosages would be influenced by improved raw water quality. However, the quality of water should be fairly consistent at the point that ozone is applied. Since the purpose of ozonation is to guarantee removals of any remaining offensive material, even with high quality water, the amount of ozone applied would not be



U.S. ARMY CORPS OF ENGINEERS

MERRIMACK RIVER
TREATMENT PLANT STUDY

VARIATIONS IN
ANNUAL COST OF OPERATION
FIGURE 6

HAYDEN, HARDING & BUCHANAN, INC.
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diminished.

The primary reduction in operating costs would be in the cost of chemicals and therefore also in the cost of operating the alum recovery plant. Depending on the improvement in river water quality, these reductions could be as much as $1,000 per year per mgd of design capacity. The effect of improvement in river water quality is indicated on Curve B of Figure 6.

Failure to implement treatment of waste discharges will result in a deterioration of river water quality. The degree of deterioration which would be the result of lack of implementation is difficult to estimate.

Quality deterioration would most significantly affect the operations costs of chemicals and alum recovery processes. Although effected to a lesser extent, the operations costs for ozone, power, and labor would also be increased. With severe quality deterioration, chemical and alum recovery costs might double. We estimate that increases in all operating costs could result in raising the total annual operating costs for any particular capacity treatment facility by as much as fifty percent of the anticipated total annual cost of operation. This increased cost is shown by Curve C of Figure 6.

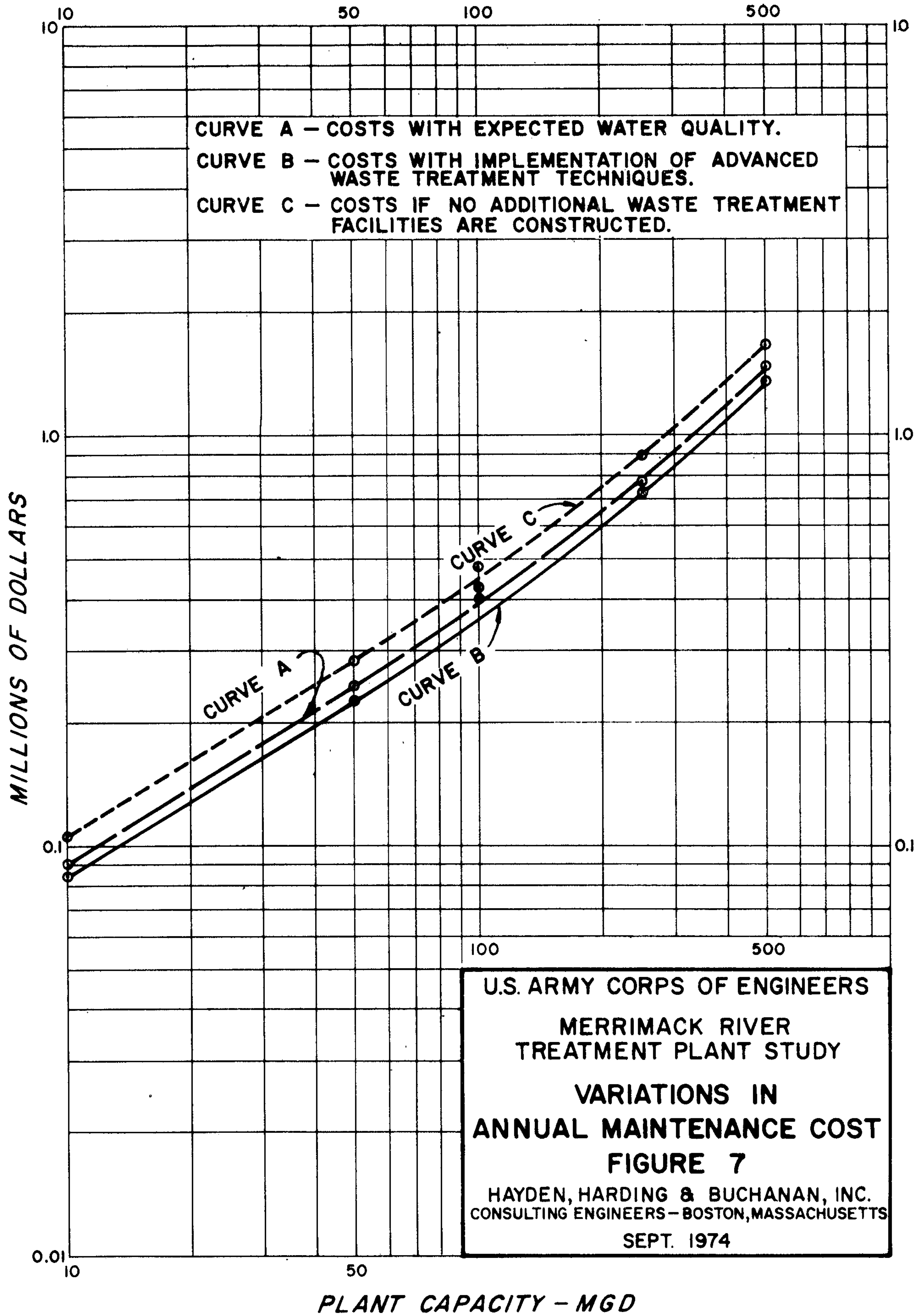
D. MAINTENANCE COSTS

As with operations costs, maintenance costs would be affected by the quantity as well as the quality of the raw water. However, variations in flow or in raw water quality would, in our estimation, have less effect on the costs of maintenance than on costs of operation. When not in use, items of equipment still require periodic maintenance. Buildings and grounds are not affected by plant production and still must be cleaned and repainted. Also,with the most adverse water quality to be anticipated, the life expectancy of the equipment should not be significantly diminished.

Since flow variations for any particular capacity treatment plant have been assumed to be negligible, only variations in water quality would affect maintenance costs. The item of cost most sensitive to quality fluctuations is carbon regeneration. Annual costs for regeneration of carbon are estimated to be doubled under the worst conditions anticipated and halved if advanced waste treatment techniques are implemented. The effect of variations due to changes in water quality of the cost of carbon regeneration and other maintenance items on the total annual maintenance cost would be an increase of about 15 percent in the worst case and a drop of six to eight percent with the expected best quality water. These effects are illustrated on Figure 7, Variations in Annual Cost of Maintenance. Curve A indicates the estimated annual maintenance for the expected river water quality. Curve B indicates the reduced maintenance cost resulting from implementation of advanced waste treatment techniques. Curve C indicates the effect of failure to provide secondary treatment of waste flows.

E. ADDITIONAL TREATMENT PROCESS REQUIREMENTS

Should a subsequent determination be made to provide for removal of dissolved solids, then the costs of construction, operation, and maintenance for these facilities would need to be ascertained. The addition of these costs to the values estimated for the proposed treatment processes would increase those values significantly.



U.S. ARMY CORPS OF ENGINEERS

MERRIMACK RIVER
TREATMENT PLANT STUDY

VARIATIONS IN ANNUAL MAINTENANCE COST

FIGURE 7

HAYDEN, HARDING & BUCHANAN, INC.
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SECTION IX

PRELIMINARY DESIGN

A. GENERAL

As part of this report, a preliminary design of a water treatment plant has been prepared. Discussions with representatives of the Corps of Engineers indicated that the preliminary design be based on a plant capacity of 50 mgd.

B. PLANT LOCATION

Two locations were selected to be investigated for use as potential sites for the plant. Some of the factors used to determine potential sites were:

1. Raw water quality
2. Sufficient land area for plant
3. Access to the river
4. Access to highways
5. Access to a railroad
6. Availability of power

Review of water quality data indicated that the water above the Pawtucket Dam in Lowell should be somewhat better than the water quality below Lowell.

Inspection of U.S. Geological Survey maps indicated the potential sites. Two sites seemed to fit the basic criteria requirements.

One site was in North Chelmsford on the west bank of the river opposite Tyng's Island. The USGS map showed ground elevations between 100 and 120 feet above mean sea level.

The second site was in Tyngsboro, also on the west bank of the river, and about 1/2 mile north of the Tyngsboro Bridge. Ground elevations are shown to be on the order of 110 feet above mean sea level.

C. SITE INSPECTION

A visit was made to each site in order to know the site better as well as to check for possible problems. While both sites could be used for a water treatment plant of 50 mgd capacity, the site in Chelmsford is being developed for

Industrial use. A printing house is presently operating on a portion of the site. Since other portions of the site are probably taken by other industries, expansion of a water treatment plant could be difficult. Consequently, we suggest that the Chelmsford site be considered as unavailable at this time.

The Tyngsboro site appears to be available since no permanent structures are present. The land is gently rolling croplands and woods. Some improvement of roads and construction of rail sidings and access roads will be required to develop the site for use as a water treatment facility.

Use of the Tyngsboro site has been assumed for the purpose of the preliminary design.

D. PLANT DESCRIPTION

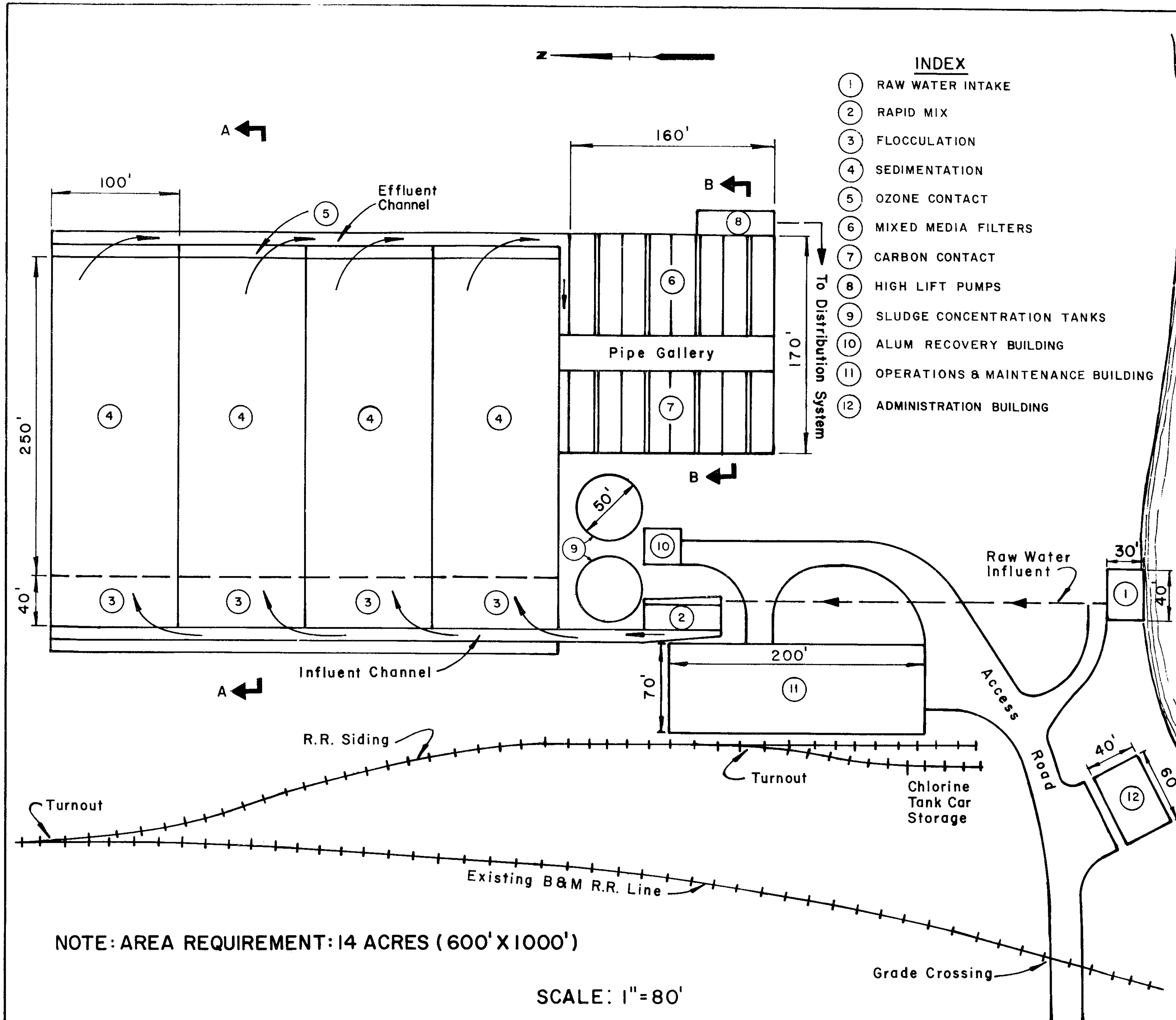
The proposed plant would have an intake located at the bank of the river at the South end of the site. As described earlier under Chapter V, Selected Unit Processes, the Intake would also house screens, raw water pumps and other equipment.

Water would be pumped to a rapid mix chamber where chemicals added to the water would be mixed. The water would be treated by flocculation, sedimentation, filtration and carbon contact then discharged to a clear well where the water would receive final ozonation and chlorination. From the clear well the water would be pumped to the points of distribution.

The proposed facility would have chemical storage and handling facilities, alum recovery units and carbon regeneration equipment plus offices, laboratories, shops, and garages. The grounds would be landscaped to make the external aspects of the plant amenable to the surroundings.

E. PLANT LAYOUT

A tentative arrangement of the various operations is shown on Figures 8,9,10. Tentative sizing has been shown on Figure 8. The land requirement for the plant would be about 14 acres. This area should provide sufficient space for landscaping and other exterior land requirements.



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MERRIMACK RIVER
TREATMENT PLANT STUDY

SITE PLAN
FIGURE 8

HAYDEN, HARDING & BUCHANAN, INC.
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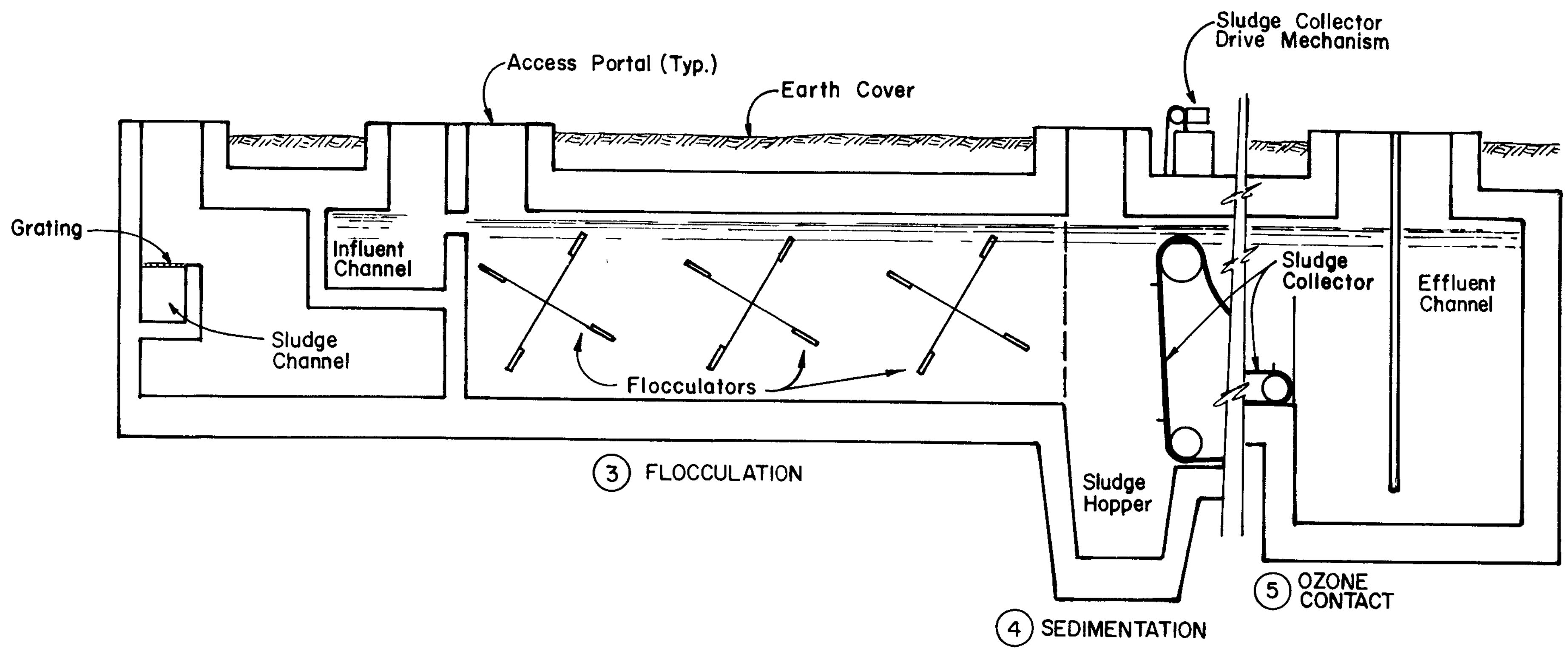

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MERRIMACK RIVER
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SECTION A-A
FIGURE 9

HAYDEN, HARDING & BUCHANAN, INC.
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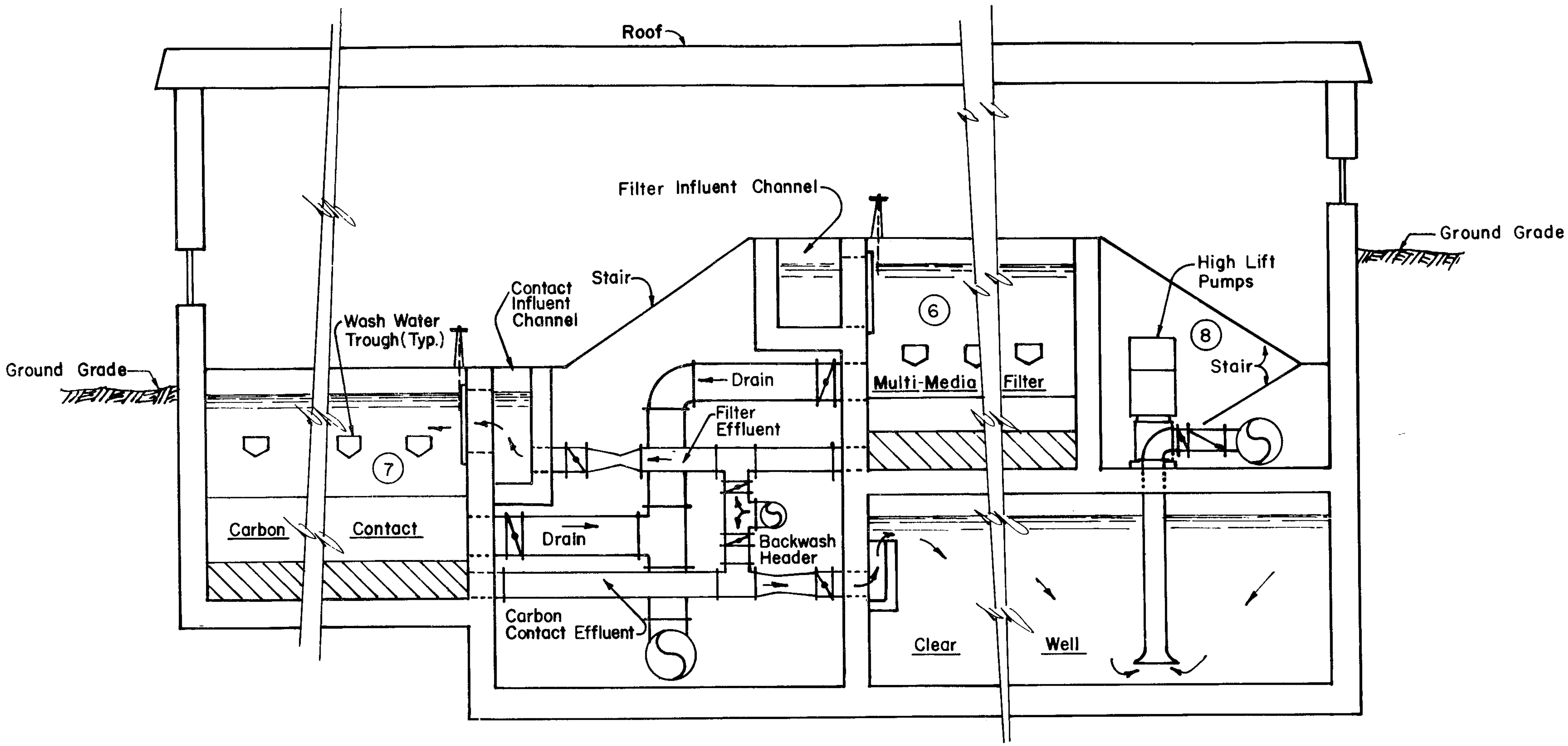

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MERRIMACK RIVER
TREATMENT PLANT STUDY

SECTION B-B
FIGURE 10

HAYDEN, HARDING & BUCHANAN, INC.
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The proposed plant is estimated to cost in the order of \$23,250,000 to construct. A detailed breakdown of the construction costs is a part of Appendix B.

This estimate is based on there being only a nominal amount of rock excavation and disposal of excess soil on the site. Soil borings should be made to ascertain the character of the strata underlying the proposed site. However, the geology of the Merrimack River valley indicates that the overburden soil depths should be sufficient to obviate the need for extensive ledge removal. Also the type of soil found at the site should be usable as fill material for regrading.

G. ANNUAL OPERATION AND MAINTENANCE COSTS

As detailed in Appendix B, the estimated annual cost of operating a 50 mgd water treatment plant would be \$1,070,000. In addition to the cost of operation, the annual maintenance cost is estimated to be \$245,000. This annual maintenance cost includes upkeep and replacement of machinery.

Based on 50 mgd and an annual cost of \$1,315,000, the unit cost of water treatment would be on the order of 7.2 cents per thousand gallons. This cost is for treatment only. The estimate of unit cost does not include the cost of pumping the treated water to the points of delivery or any of the costs associated with the operation of a distribution system.

None of the fixed costs associated with the amortization of the cost of construction have been included in the annual costs.

APPENDIX A

MERRIMACK RIVER WATER QUALITY DATA

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PARAMETER				NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
00008	LAB	IDENT.	NUMBER	1	1743.00					1743.00	1743.00	72/12/05	72/12/05
00010	WATER	TEMP	CENT	53	11.6977	94.9989	9.74674	.833219	1.33882	27.2000	.000000	69/08/19	72/12/05
00020	AIR	TEMP	CENT	52	14.5557	98.6230	9.93091	.682268	1.37717	31.2000	-.900E+01	69/08/19	72/12/05
00060	STREAM	FLOW	CFS	54	6981.61	.356E+08	5970.13	.855122	812.432	25000.0	1057.00	69/08/19	72/12/05
00070	TURB	JKSN	JTU	39	5.12564	24.2946	4.92895	.961627	.789264	30.0000	.900000	69/09/15	72/12/05
00075	TURB	HLGE	PPM SIO2	1	3.40000					3.40000	3.40000	69/08/19	69/08/19
00080	COLOR	PT-CO	UNITS	4	33.7500	133.583	11.5578	.342454	5.77891	50.0000	25.0000	69/09/15	72/09/11
00095	CNDUCTVY	AT 25C	MICROMHO	54	105.518	706.151	26.5735	.251837	3.61620	161.000	50.0000	69/08/19	72/12/05
00300	DO		MG/L	52	9.22111	10.8667	3.29647	.357492	.457138	14.0000	4.60000	69/08/19	72/11/06
00310	BOD	5 DAY	MG/L	4	3.57500	3.78916	1.94658	.544497	.973288	6.20000	1.50000	69/09/15	72/09/11
00335	COD	LOWLEVEL	MG/L	40	15.8500	56.1309	7.49206	.472685	1.18460	47.0000	4.00000	69/08/19	72/12/05
00400	PH		SU	52	6.89478	.071409	.267224	.038757	.037057	7.40000	6.20000	69/08/19	72/12/05
00405	CO2		MG/L	1	1.60000					1.60000	1.60000	72/09/11	72/09/11
00410	T ALK	CACO3	MG/L	5	17.0000	56.5000	7.51665	.442156	3.36155	25.0000	8.00000	69/09/15	72/09/11
00435	T ACDITY	CACO3	MG/L	4	3.40000	9.84000	3.13688	.922611	1.56844	7.60000	.000000	69/09/15	72/09/11
00440	HCO3 ION	HCO3	MG/L	3	27.0000	7.00000	2.64575	.097991	1.52752	30.0000	25.0000	71/07/13	72/09/11
00445	CO3 ION	CO3	MG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	71/07/13	72/09/11
00500	RESIDUE	TOTAL	MG/L	1	103.000					103.000	103.000	69/09/15	69/09/15
00505	RESIDUE	TOT VOL	MG/L	1	23.0000					23.0000	23.0000	71/09/13	71/09/13
00515	RESIDUE	DISS-105 C	MG/L	2	86.0000	338.000	18.3848	.213776	13.0000	99.0000	73.0000	71/09/13	72/09/11
00525	RESIDUE	FIX FLT	MG/L	1	4.00000					4.00000	4.00000	71/09/13	71/09/13
00530	RESIDUE	TOT NFLT	MG/L	5	7.80000	2.70007	1.64319	.210665	.734857	10.0000	6.00000	69/09/15	72/09/11
00550	OIL GRSE	TOTAL	MG/L	4	88.5000	25925.7	161.014	1.81937	80.5072	330.000	5.00000	70/06/08	72/09/11
00600	TOTAL N	N	MG/L	1	3.85000					3.85000	3.85000	71/09/13	71/09/13
00605	ORG N	N	MG/L	5	.952000	.290370	.538860	.566029	.240985	1.60000	.400000	69/09/15	71/09/13
00610	NH3-N	TOTAL	MG/L	6	1.36833	.351216	.592635	.433107	.241942	2.00000	.510000	69/09/15	72/09/11
00615	NO2-N	TOTAL	MG/L	6	.024333	.000265	.016269	.668572	.006642	.050000	.000000	69/09/15	72/09/11
00618	NO3-N	DISS	MG/L	2	.200000	.000000	.000000		.000000	.200000	.200000	72/11/06	72/12/05
00620	NO3-N	TOTAL	MG/L	38	.511314	.354566	.595454	1.16456	.096595	2.70000	.090000	69/08/19	72/10/03
00625	TOT KJEL	N	MG/L	40	1.35600	.556370	.745902	.550076	.117937	3.40000	.390000	69/08/19	72/12/05
00650	T PO4	PO4	MG/L	17	.361176	.018098	.134531	.372479	.032628	.580000	.150000	70/10/05	72/11/06
00665	PHOS-T	P-WET	MG/L	40	.147400	.006973	.083505	.566524	.013203	.530000	.050000	69/08/19	72/12/05
00666	PHOS-D	P-WET	MG/L	2	.100000	.000800	.028284	.282843	.020000	.120000	.080000	69/09/15	71/09/13
00720	CYANIDE	CN	MG/L	4	.022500	.000692	.026300	1.16887	.013150	.060000	.000000	70/06/08	72/09/11
00900	TOT HARD	CACO3	MG/L	4	23.2500	1.58333	1.25831	.054121	.629153	25.0000	22.0000	69/09/15	72/09/11
00902	NC HARD	CACO3	MG/L	2	1.00000	2.00000	1.41421	1.41421	1.00000	2.00000	.000000	71/09/13	72/09/11
00915	CALCIUM	CA,DISS	MG/L	3	7.66667	.333405	.577412	.075315	.333369	8.00000	7.00000	71/07/13	72/09/11
00925	MGNSIUM	MG,DISS	MG/L	2	1.15000	.004999	.070705	.061482	.049996	1.20000	1.10000	71/09/13	72/09/11
00930	SODIUM	NA,DISS	MG/L	2	14.0000	8.00000	2.82843	.202030	2.00000	16.0000	12.0000	71/09/13	72/09/11

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PARAMETER				NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
00931	SODIUM	ADSBTION	RATIO	2	1.25000	.045001	.212134	.169708	.150002	1.40000	1.10000	71/09/13	72/09/11
00932	PERCENT	SODIUM	%	2	54.0000	8.00000	2.82843	.052378	2.00000	56.0000	52.0000	71/09/13	72/09/11
00935	PTSSIUM	K,DISS	MG/L	2	1.70000	.080000	.282843	.166378	.200000	1.90000	1.50000	71/09/13	72/09/11
00940	CHLORIDE	CL	MG/L	5	30.9000	616.051	24.8204	.803248	11.1000	75.0000	17.0000	69/09/15	72/09/11
00945	SULFATE	SO4	MG/L	4	15.2500	15.5833	3.94757	.258857	1.97379	21.0000	12.0000	69/09/15	72/09/11
00950	FLUORIDE	F,DISS	MG/L	2	.400000	.020000	.141421	.353553	.100000	.500000	.300000	71/09/13	72/09/11
00955	SILICA	DISOLVED	MG/L	1	4.10000					4.10000	4.10000	71/09/13	71/09/13
01000	ARSENIC	AS,DISS	UG/L	5	1.40000	9.80000	3.13049	2.23607	1.40000	7.00000	.000000	69/09/15	72/09/11
01005	BARIUM	BA,DISS	UG/L	3	14.6667	17.3335	4.16335	.283865	2.40371	18.0000	10.0000	70/12/07	71/07/13
01010	BERYLIUM	BE,DISS	UG/L	3	.233333	.003333	.057735	.247436	.033333	.300000	.200000	70/12/07	71/07/13
01015	BISMUTH	BI,DISS	UG/L	3	2.00000	.000000	.000000		.000000	2.00000	2.00000	70/12/07	71/07/13
01020	BORON	B,DISS	UG/L	3	19.3333	.333740	.577702	.029881	.333537	20.0000	19.0000	70/12/07	71/07/13
01025	CADMIUM	CD,DISS	UG/L	4	12.2500	173.583	13.1751	1.07552	6.58755	30.0000	.000000	70/10/14	71/07/13
01030	CHROMIUM	CR,DISS	UG/L	5	4.80000	22.7000	4.76445	.992594	2.13073	11.0000	.000000	69/09/15	71/07/13
01032	CHROMIUM	HEX-VAL	UG/L	1	.000000					.000000	.000000	70/10/14	70/10/14
01035	COBALT	CO,DISS	UG/L	4	1.55000	1.43000	1.19583	.771501	.597913	3.00000	.300000	70/10/14	71/07/13
01040	COPPER	CU-DISS	UG/L	6	12.1667	52.1667	7.22266	.593643	2.94864	20.0000	.000000	69/09/15	72/09/11
01046	IRON	FE,DISS	UG/L	6	276.666	7306.77	85.4797	.308963	34.8969	420.000	200.000	69/09/15	72/09/11
01049	LEAD	PB,DISS	UG/L	6	9.50000	9.90000	3.14643	.331203	1.28452	13.0000	4.00000	69/09/15	71/07/13
01056	MANGNESE	MN,DISS	UG/L	6	59.6667	109.870	10.4819	.175674	4.27922	70.0000	40.0000	69/09/15	72/09/11
01060	MOLY	MO.DISS	UG/L	3	.500000	.040001	.200002	.400004	.115471	.700000	.300000	70/12/07	71/07/13
01065	NICKEL	NI,DISS	UG/L	3	5.33333	.333343	.577359	.108255	.333338	6.00000	5.00000	70/12/07	71/07/13
01075	SILVER	AG,DISS	UG/L	3	.186667	.014533	.120554	.645826	.069602	.300000	.060000	70/12/07	71/07/13
01080	STRONTUM	SR,DISS	UG/L	3	47.3333	302.336	17.3878	.367348	10.0389	67.0000	34.0000	70/12/07	71/07/13
01085	VANADIUM	V,DISS	UG/L	3	.766666	.063334	.251662	.328255	.145297	1.00000	.500000	70/12/07	71/07/13
01090	ZINC	ZN,DISS	UG/L	6	41.8333	2576.17	50.7559	1.21329	20.7210	140.000	.000000	69/09/15	71/07/13
01100	TIN	SN,DISS	UG/L	3	1.96667	1.10334	1.05040	.534101	.606447	3.00000	.900000	70/12/07	71/07/13
01106	ALUMINUM	AL,DISS	UG/L	5	157.000	44945.0	212.002	1.35033	94.8103	510.000	.000000	69/09/15	71/07/13
01120	GALLIUM	GA,DISS	UG/L	2	.300000	-.596E-07	.000000		.000000	.300000	.300000	71/01/01	71/07/13
01125	GERMANUM	GE,DISS	UG/L	3	2.00000	.000000	.000000		.000000	2.00000	2.00000	70/12/07	71/07/13
01130	LITHIUM	LI,DISS	UG/L	3	4.00000	27.0000	5.19615	1.29904	3.00000	10.0000	1.00000	70/12/07	71/07/13
01135	RUBIDIUM	RB,DISS	UG/L	2	2.50000	.500000	.707107	.282843	.500000	3.00000	2.00000	70/12/07	71/01/01
01150	TITANIUM	TI,DISS	UG/L	3	1.33333	.333335	.577352	.433014	.333334	2.00000	1.00000	70/12/07	71/07/13
01160	ZIRCONUM	ZR,DISS	UG/L	2	1.75000	3.12500	1.76777	1.01015	1.25000	3.00000	.500000	71/01/01	71/07/13
01503	ALPHA	DISOLVED	PC/L	2	.600000	.080000	.282843	.471405	.200000	.800000	.400000	69/09/15	70/08/31
01505	ALPHA	SUSP	PC/L	2	.350000	.045000	.212132	.606092	.150000	.500000	.200000	69/09/15	70/08/31
01515	ALPHA-D	AS U-NAT	PC/L	2	.450000	.045000	.212132	.471405	.150000	.600000	.300000	71/09/13	72/09/11
01516	ALPHA-S	AS U-NAT	PC/L	2	.150000	.005000	.070711	.471404	.050000	.200000	.100000	71/09/13	72/09/11
03503	BETA	DISOLVED	PC/L	2	5.75000	.005005	.070745	.012304	.050024	5.80000	5.70000	69/09/15	70/08/31
03505	BETA	SUSP	PC/L	2	2.45000	4.80500	2.19203	.894707	1.55000	4.00000	.900000	69/09/15	70/08/31

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PARAMETER	NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
03515 BETA-D AS CS137 PC/L	2	3.90000	.179993	.424255	.108783	.299994	4.20000	3.60000	71/09/13	72/09/11
03516 BETA-S AS CS137 PC/L	2	1.05000	.125001	.353555	.336719	.250001	1.30000	.800000	71/09/13	72/09/11
31501 TOT COLI MFIMENDO /100ML	52	42126.9	.203E+10	45129.2	1.07127	6258.29	260000	3200.00	69/08/19	72/12/05
31616 FEC COLI MFM-FCBR /100ML	51	989.157	688410	829.705	.838800	116.182	4200.00	47.0000	69/08/19	72/12/05
32230 CHLRPHYL A MG/L	38	1.08390	12.0794	3.47554	3.20650	.563807	18.0000	.000000	69/10/06	72/12/05
32730 PHENOLS UG/L	4	6.00000	44.6667	6.68331	1.11388	3.34166	14.0000	.000000	70/06/08	72/09/11
38260 MBAS MG/L	40	.051250	.000268	.016360	.319213	.002587	.100000	.020000	69/08/19	72/12/05
39330 ALDRIN WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39340 BHC WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39360 DDD WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39365 DDE WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39370 DDT WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39380 DIELDRIN WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39390 ENDRIN WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39398 ETHION WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39410 HCHLR WHL SMPL UG/L	3	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39516 PCBS WHL SMPL UG/L	2	.000000	.000000	.000000		.000000	.000000	.000000	72/07/11	72/09/11
39530 MALATHN WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39540 PARATHN WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39570 DIAZINON WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39600 MPARATHN WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39730 2,4-D WHL SMPL UG/L	4	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39740 2,4,5-T WHL SMPL UG/L	4	.002500	.000025	.005000	2.00000	.002500	.010000	.000000	69/09/15	71/09/13
39760 SILVEX WHL SMPL UG/L	4	.000000	.000000	.000000		.000000	.000000	.000000	69/09/15	71/09/13
39786 TRITHION WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
39790 MTRTHION WHL SMPL UG/L	1	.000000					.000000	.000000	71/09/13	71/09/13
70300 RESIDUE DISS-180 C MG/L	4	85.2500	138.250	11.7580	.137923	5.87899	99.0000	72.0000	69/09/15	72/09/11
70301 DISS SOL SUM MG/L	2	77.0000	200.000	14.1421	.183664	10.0000	87.0000	67.0000	71/09/13	72/09/11
70302 DISS SOL TONS/DAY	2	566.000	19602.0	140.007	.247362	99.0000	665.000	467.000	71/09/13	72/09/11
70303 DISS SOL TONS PER ACRE-FT	3	.113333	.000233	.015275	.134783	.008819	.130000	.100000	70/08/31	72/09/11
71825 T ACDTY AS H MG/L	1	.000000					.000000	.000000	72/09/11	72/09/11
71845 AMMONIA NH4 MG/L	4	1.97000	.777731	.881890	.447660	.440945	2.58000	.660000	71/07/13	72/09/11
71850 NITRATE NO3 MG/L	26	1.86807	5.56721	2.35949	1.26307	.462735	12.0000	.400000	70/10/05	72/12/05
71855 NITRITE NO2 MG/L	1	.090000					.090000	.090000	72/09/11	72/09/11
71886 TOTAL P AS PO4 MG/L	8	.555000	.031943	.178725	.322028	.063189	.830000	.300000	71/07/13	72/02/07
71890 MERCURY HG,DISS UG/L	3	.600000	.310000	.556776	.927961	.321455	1.20000	.100000	70/08/31	71/09/13
71900 MERCURY HG,TOTAL UG/L	2	.500000	.000000	.000000		.000000	.500000	.500000	70/10/14	72/09/11
80030 ALPHA-D AS U-NAT UG/L	2	1.30000	.500001	.707107	.543929	.500001	1.80000	.800000	71/09/13	72/09/11
80040 ALPHA-S AS U-NAT UG/L	2	.550000	.045001	.212133	.385697	.150001	.700000	.400000	71/09/13	72/09/11
80050 BETA-D AS SR-Y-90, PC/L	2	3.10000	.179993	.424255	.136857	.299994	3.40000	2.80000	71/09/13	72/09/11

MERRIMACK RIVER
ABOVE LOWELL

STORET DATE 73/03/30

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MERRIMACK RIVER ABOVE LOWELL MAS
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INDEX 0109001
MILES 43.47

PARAMETER	NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
80060 BETA-S AS SR-Y- 90, PC/L	2	.950000	.125000	.353553	.372161	.250000	1.20000	.700000	71/09/13	72/09/11

**MERRIMACK RIVER
ABOVE LOWELL**

STORET DATE 73/03/30

01100000
42 38 45.0 071 17 56.0 2
MERRIMACK R BL CONCORD R ATLOWEL
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PARAMETER		NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
01032 CHROMIUM HEX-VAL	UG/L	1	.000000					.000000	.000000	70/10/16	70/10/16
01035 COBALT CO,DISS	UG/L	1	4.00000					4.00000	4.00000	70/10/16	70/10/16
01040 COPPER CU-DISS	UG/L	8	27.5000	250.000	15.8114	.574959	5.59017	60.0000	10.0000	53/10/19	66/06/28
01045 IRON TOTAL	UG/L	2	210.000	9800.00	98.9949	.471404	70.0000	280.000	140.000	68/01/30	68/02/16
01046 IRON FE,DISS	UG/L	28	236.798	36735.2	191.664	.809400	36.2211	1000.00	.340000	53/10/19	72/09/11
01049 LEAD PB,DISS	UG/L	7	44.8571	2790.81	52.8281	1.17770	19.9671	120.000	10.0000	66/04/19	70/10/16
01055 MANGNESE MN	UG/L	7	95.7148	2228.58	47.2078	.493216	17.8429	180.000	40.0000	66/04/19	68/02/16
01056 MANGNESE MN,DISS	UG/L	25	52.8032	1870.65	43.2510	.819099	8.65020	180.000	.000000	53/10/19	72/09/11
01065 NICKEL NI.DISS	UG/L	6	6.00000	15.6000	3.94968	.658280	1.61245	10.0000	.000000	66/04/19	66/06/28
01080 STRONTUM SR,DISS	UG/L	6	43.3333	426.669	20.6560	.476676	8.43277	70.0000	30.0000	66/04/19	66/06/28
01090 ZINC ZN,DISS	UG/L	9	63.3333	1200.00	34.6410	.546964	11.5470	100.000	.000000	53/10/19	70/10/16
01105 ALUMINUM AL,TOT	UG/L	3	533.333	143333	378.594	.709864	218.581	800.000	100.000	66/04/19	66/06/28
01106 ALUMINUM AL,DISS	UG/L	5	462.000	114720	338.703	.733124	151.473	810.000	100.000	53/10/19	66/06/28
01130 LITHIUM LI,DISS	UG/L	5	100.000	30000.0	173.205	1.73205	77.4597	400.000	.000000	53/10/19	66/06/28
31501 TOT COLI MFIMENDO	/100ML	17	49823.5	.197E+10	44435.6	.891860	10777.2	150,000	13,000.0	69/10/06	70/08/31
31616 FEC COLI MFM-FCBR	/100ML	17	2664.71	5238365	2288.75	.858912	555.103	10000.0	850.000	69/10/06	70/08/31
32730 PHENOLS	UG/L	11	12000.0	.182E+09	13496.1	1.12467	4069.22	50000.0	6000.00	66/04/19	67/09/12
38260 MBAS	MG/L	1	.060000					.060000	.060000	71/06/07	71/06/07
70300 RESIDUE DISS-180 C	MG/L	48	73.6875	421.538	20.5314	.278628	2.96345	133.000	30.0000	53/10/19	71/06/07
70301 DISS SOL SUM	MG/L	38	63.9737	187.542	13.6946	.214066	2.22156	91.0000	28.0000	66/01/12	72/09/11
70302 DISS SOL TONS/DAY		39	975.590	892591	944.770	.968409	151.284	5290.00	51.0000	53/10/19	72/09/11
70303 DISS SOL TONS PER	ACRE-FT	52	.100961	.000754	.027459	.271981	.003808	.180000	.040000	53/10/19	72/09/11
71825 T ACDITY AS H	MG/L	1	.000000					.000000	.000000	72/09/11	72/09/11
71845 AMMONIA NH4	MG/L	14	.679285	.486130	.697230	1.02642	.186343	2.58000	.080000	66/03/15	72/09/11
71850 NITRATE NO3	MG/L	52	2.81269	4.14601	2.03618	.723926	.282367	9.80000	.160000	53/10/19	72/09/11
71855 NITRITE NO2	MG/L	11	.472727	.834122	.913303	1.93199	.275371	3.16000	.020000	69/07/08	72/09/11
71885 IRON FE	UG/L	5	186.000	10180.0	100.896	.542451	45.1221	260.000	20.0000	66/04/19	67/09/21
71886 TOTAL P AS PO4	MG/L	9	.371111	.054736	.233958	.630427	.077986	.890000	.040000	69/03/12	71/12/06
71890 MERCURY HG,DISS	UG/L	1	4.70000					4.70000	4.70000	70/10/16	70/10/16
71900 MERCURY HG,TOTAL	UG/L	1	.500000					.500000	.500000	70/10/16	70/10/16

MERRIMACK RIVER
BELOW THE CONCORD RIVER
AT LOWELL

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MERRIMACK R BL CONCORD R ATLOWEL
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STORET DATE 73/03/30

112WRD 06111204
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PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
00008 LAB	IDENT.	NUMBER	1	2820.00					2820.00	2820.00	71/06/07	71/06/07
00010 WATER	TEMP	CENT	46	12.0264	85.7427	9.25974	.769948	1.36527	28.0000	.000000	54/04/30	72/09/11
00020 AIR	TEMP	CENT	15	15.8300	153.407	12.3858	.782423	3.19799	42.9500	.000000	69/03/12	72/09/11
00060 STREAM	FLOW	CFS	55	6143.82	.306F+08	5537.12	.901251	746.625	34900.0	700.000	53/10/19	72/09/11
00065 STREAM	STAGE	FEET	9	42.8022	37.2139	6.10032	.142523	2.03344	49.5300	28.0000	69/03/12	70/07/14
00075 TURB	HLGE	PPM SIO2	2	2.50000	4.50000	2.12132	.848528	1.50000	4.00000	1.00000	66/01/12	67/07/11
00080 COLOR	PT-CO	UNITS	30	22.8666	127.982	11.3129	.494735	2.06545	50.0000	4.00000	53/10/19	71/06/07
00095 CNDUCTVY	AT 25C	MICROMHO	64	112.141	801.583	28.3122	.252471	3.53903	190.000	46.0000	53/10/19	72/09/11
00300 DO		MG/L	12	8.64166	9.05904	3.00982	.348292	.868861	14.5000	5.80000	69/09/15	72/09/11
00310 BOD	5 DAY	MG/L	12	2.91666	2.52516	1.58907	.544326	.458726	7.10000	1.40000	69/10/06	70/08/31
00400 PH		SU	64	6.47495	.204656	.452389	.069867	.056549	7.70000	5.60000	53/10/19	72/09/11
00410 T ALK	CACO3	MG/L	52	9.76923	33.7889	5.81282	.595013	.806093	30.0000	3.00000	53/10/19	72/09/11
00435 T ACDITY	CACO3	MG/L	1	.000000					.000000	.000000	72/09/11	72/09/11
00440 HCO3 ION	HCO3	MG/L	52	11.8269	49.5578	7.03973	.595229	.976235	36.0000	4.00000	53/10/19	72/09/11
00445 CO3 ION	CO3	MG/L	51	.000000	.000000	.000000		.000000	.000000	.000000	53/10/19	72/09/11
00505 RESIDUE	TOT VOL	MG/L	17	14.6471	49.3677	7.02621	.479701	1.70411	27.0000	1.00000	53/10/19	71/06/07
00600 TOTAL N	N	MG/L	2	3.58350	8.29466	2.88005	.803696	2.03650	5.62000	1.54700	72/03/06	72/09/11
00605 ORG N	N	MG/L	2	1.03000	.145802	.381841	.370720	.270002	1.30000	.760000	72/03/06	72/09/11
00610 NH3-N	TOTAL	MG/L	5	.923400	.566098	.752395	.814309	.336481	2.00000	.060000	71/03/02	72/09/11
00615 NO2-N	TOTAL	MG/L	5	.227600	.170695	.413153	1.81526	.184768	.960000	.007000	70/12/07	72/09/11
00620 NO3-N	TOTAL	MG/L	7	.866999	.525600	.724983	.836197	.274018	2.20000	.300000	70/12/07	72/09/11
00650 T PO4	PO4	MG/L	37	.724049	1.52076	1.23319	1.70318	.202735	7.80000	.110000	53/10/19	72/09/11
00660 ORTHOPO4	PO4	MG/L	7	.502857	.110591	.332552	.661324	.125693	.890000	.070000	66/01/12	66/09/21
00665 PHOS-T	P-WET	MG/L	5	.192000	.004070	.063796	.332272	.028531	.290000	.130000	71/03/02	72/09/11
00900 TOT HARD	CACO3	MG/L	52	21.2692	37.1420	6.09442	.286537	.845144	40.0000	10.0000	53/10/19	72/09/11
00902 NC HARD	CACO3	MG/L	51	11.6667	17.3468	4.16495	.356995	.583209	26.0000	2.00000	53/10/19	72/09/11
00915 CALCIUM	CA,DISS	MG/L	51	6.66273	4.01460	2.00365	.300725	.280567	13.0000	3.20000	53/10/19	72/09/11
00925 MGNSIUM	MG.DISS	MG/L	51	1.12941	.110524	.332451	.294359	.046553	2.30000	.400000	53/10/19	72/09/11
00930 SODIUM	NA,DISS	MG/L	40	11.3550	14.8182	3.84944	.339009	.608650	19.0000	2.00000	53/10/19	72/09/11
00931 SODIUM	ADSBTION	RATIO	52	1.09423	.127619	.357239	.326476	.049540	1.80000	.200000	53/10/19	72/09/11
00932 PERCENT	SODIUM	%	40	51.7500	82.5000	9.08295	.175516	1.43614	67.0000	15.0000	53/10/19	72/09/11
00933 NA+K		MG/L	12	12.1917	27.2863	5.22363	.428459	1.50793	21.0000	2.00000	66/01/12	67/02/24
00935 PTSSIUM	K,DISS	MG/L	31	1.37096	.534802	.731301	.533422	.131346	4.80000	.500000	53/10/19	72/09/11
00940 CHLORIDE	CL	MG/L	51	15.3804	27.2689	5.22196	.339521	.731221	30.0000	5.00000	53/10/19	72/09/11
00945 SULFATE	SO4	MG/L	51	13.4863	7.03023	2.65146	.196604	.371278	19.0000	8.00000	53/10/19	72/09/11
00950 FLUORIDE	F.DISS	MG/L	52	.203846	.012142	.110189	.540553	.015281	.400000	.000000	53/10/19	72/09/11
00955 SILICA	DISOLVED	MG/L	52	5.02307	2.07871	1.44177	.287031	.199938	7.20000	.100000	53/10/19	72/09/11
01000 ARSENIC	AS,DISS	UG/L	1	.000000					.000000	.000000	70/10/16	70/10/16
01025 CADMIUM	CD,DISS	UG/L	1	6.00000					6.00000	6.00000	70/10/16	70/10/16

MERRIMACK RIVER
BELOW THE CONCORD RIVER
AT LOWELL

APPENDIX B

COST ESTIMATES

CONSTRUCTION COST OF INTAKES

ITEM		UNIT COST $	PLANT CAPACITY 10 MGD No.	$	50 MGD No.	$	100 MGD No.	$	250 MGD No.	$	500 MGD No.	$
Excavation & Backfill	CY	15	800	12,000	1000	15,000	1600	24,000	3400	51,000	8400	126,000
Concrete	CY	300	550	165,000	800	240,000	1700	510,000	3300	990,000	5200	1,560,000
Building	SF	100	750	75,000	1200	120,000	2000	200,000	4500	450,000	8000	800,000
Screens	L.S.			100,000		145,000		259,000		320,000		570,000
Sluice Gates	L.S.			30,000		55,000		80,000		155,000		290,000
Pumps	Ea	15,000	4	60,000								
	Ea	20,000			6	120,000						
	Ea	30,000					6	180,000	8	240,000	16	480,000
Auxiliary Power	L.S.			15,000		65,000		120,000		270,000		500,000
Site Work	L.S.			15,000		18,000		27,000		40,000		50,000
Dewatering	L.S.			120,000		150,000		200,000		300,000		400,000
Subtotal				592,000		928,000		1,600,000		2,816,000		4,776,000
Contingencies - 25%				148,000		232,000		400,000		704,000		1,194,000
TOTAL				740,000		1,160,000		2,000,000		3,520,000		5,970,000

CONSTRUCTION COST OF RAPID MIXERS

PLANT CAPACITY

ITEM	UNIT	UNIT COST $	10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Excavation & Backfill	CY	15	600	9,000	1400	21,000	2400	36,000	5600	84,000	7800	117,000
Concrete	CY	300	120	36,000	540	162,000	800	240,000	2000	600,000	3700	1,110,000
Equipment	L.S.			15,000		30,000		50,000		100,000		195,000
Miscellaneous	L.S.			4,000		11,000		22,000		40,000		74,000
Subtotal				64,000		224,000		348,000		824,000		1,496,000
Contingencies 25%				16,000		56,000		87,000		206,000		374,000
TOTAL				80,000		280,000		435,000		1,030,000		1,870,000

CONSTRUCTION COST OF FLOCCULATION FACILITIES

ITEM	UNIT	UNIT COST $	PLANT CAPACITY 10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Excavation & Backfill	CY	15	2400	36,000	10,000	150,000	20,000	300,000	42,000	630,000	82,000	1,230,000
Concrete	CY	300	600	180,000	2,400	720,000	4,700	1,410,000	9,400	2,820,000	19,000	5,700,000
Equipment	L.S.			100,000		350,000		700,000		1,340,000		2,600,000
Miscellaneous	L.S.			12,000		20,000		30,000		50,000		70,000
Subtotal				328,000		1,240,000		2,440,000		4,840,000		9,600,000
Contingencies 25%				82,000		310,000		610,000		1,210,000		2,400,000
TOTAL				410,000		1,550,000		3,050,000		6,050,000		12,000,000

CONSTRUCTION COST OF SEDIMENTATION FACILITIES

ITEM	UNIT	UNIT COST $	PLANT CAPACITY 10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Excavation & Backfill	CY	15	13000	195,000	61,000	915,000	121,000	1,815,000	282,000	4,230,000	560,000	8,400,000
Concrete	CY	300	3500	1,050,000	16,000	4,800,000	32,000	9,600,000	77,000	23,100,000	154,000	46,200,000
Equipment	L.S.			190,000		900,000		1,750,000		3,000,000		6,000,000
Miscellaneous	L.S.			5,000		25,000		35,000		70,000		120,000
Subtotal				1,440,000		6,640,000		13,200,000		30,400,000		60,720,000
Contingencies 25%				360,000		1,660,000		3,300,000		7,600,000		15,180,000
TOTAL				1,800,000		8,300,000		16,500,000		38,000,000		75,900,000

CONSTRUCTION COST OF SAND FILTERS AND CARBON CONTACT BEDS

ITEM	UNIT	UNIT COST $	PLANT CAPACITY 10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Excavation & Backfill	CY	15	6700	100,500	21,500	322,500	39,000	585,000	88,000	1,320,000	175,000	2,625,000
Concrete	CY	300	1800	540,000	5,400	1,620,000	10,000	3,000,000	21,500	6,450,000	42,700	12,810,000
Building	SF	60	8000	480,000	27,200	1,632,000	54,000	3,240,000	121,500	7,290,000	243,000	14,580,000
Filter Valves & Controls	L.S.			176,000		350,000		590,000		975,000		1,885,000
Media-Mixed	L.S.			54,500		105,000		175,000		395,000		700,000
GAC	L.S.			73,500		350,000		685,000		1,630,000		3,150,000
Filter Accessories	SF	30	3150	94,500	15,750	472,500	31,500	945,000	72,750	2,182,500	157,500	4,725,000
Piping				20,000		50,000		125,000		275,000		550,000
Miscellaneous				21,000		58,000		95,000		162,500		375,000
Subtotal				1,560,000		4,960,000		9,440,000		20,680,000		41,400,000
Contingencies 25%				390,000		1,240,000		2,360,000		5,170,000		10,350,000
TOTAL				1,950,000		6,200,000		11,800,000		25,850,000		51,750,000

CONSTRUCTION COST OF ALUM RECOVERY PLANT

ITEM	UNIT	UNIT COST $	PLANT CAPACITY 10 MGD		50 MGD		100 MGD		250 MGD		500 MGD	
			No.	$	No.	$	No.	$	No.	$	No.	$
Sludge Thickener Tanks	L.S.			100,000		400,000		600,000		1,300,000		2,400,000
Control Building	SF	60	1000	60,000	1500	90,000	2000	120,000	2500	150,000	3000	180,000
Filter Presses	L.S.			240,000		480,000		700,000		900,000		1,250,000
Acid Storage and Feed	L.S.			15,000		40,000		60,000		100,000		130,000
Piping	L.S.			25,000		70,000		120,000		150,000		200,000
Subtotal				440,000		1,080,000		1,600,000		2,600,000		4,160,000
Contingencies 25%				110,000		270,000		400,000		650,000		1,040,000
TOTAL				550,000		1,350,000		2,000,000		3,250,000		5,200,000

CONSTRUCTION COST OF CARBON REGENERATION FACILITIES

PLANT CAPACITY

ITEM	UNIT	UNIT COST $	10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Multiple Hearth Furnace				190,000		400,000		550,000		700,000		800,000
Carbon Storage Tanks				15,000		30,000		50,000		100,000		180,000
Pumps & Piping				25,000		40,000		60,000		80,000		100,000
Building	SF	60	1500	90,000	3500	210,000	4000	240,000	5000	300,000	6000	360,000
Subtotal				320,000		680,000		900,000		1,180,000		1,440,000
Contingencies 25%				80,000		170,000		225,000		295,000		360,000
TOTAL				400,000		850,000		1,125,000		1,475,000		1,800,000

CONSTRUCTION COST OF CHEMICAL STORAGE

ITEM	UNIT	UNIT COST $	10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Bulk Storage	L.S.			32,000		40,000		48,000		125,000		160,000
Chemical Feeders *	L.S.			47,000		58,000		90,000		180,000		240,000
Ozone Equipment & Installation	L.S.			160,000		760,000		1,500,000		2,980,000		5,900,000
Chemical Handling Equipment	L.S.			15,000		30,000		110,000		170,000		230,000
Rail Siding	L.S.			--		60,000		76,000		105,000		130,000
Building	SF	60	3100	186,000	3400	204,000	5600	336,000	10,000	600,000	17,000	1,020,000
Subtotal				440,000		1,152,000		2,160,000		4,160,000		7,680,000
Contingencies 25%				110,000		288,000		540,000		1,040,000		1,920,000
TOTAL				550,000		1,440,000		2,700,000		5,200,000		9,600,000

* Lime, Alum, Gaseous Chlorine, Potassium Permanganate and Polyelectrolyte

CONSTRUCTION COST OF TOTAL WATER TREATMENT PLANT

PLANT CAPACITY

ITEM	10 MGD Thousands of $	50 MGD Thousands of $	100 MGD Thousands of $	250 MGD Thousands of $	500 MGD Thousands of $
Intake	740	1,160	2,000	3,520	5,970
Rapid Mixer	80	280	435	1,030	1,870
Flocculation	410	1,550	3,050	6,050	12,000
Sedimentation	1,800	8,300	16,500	38,000	75,900
Filtration	1,950	6,200	11,800	25,850	51,750
Alum Recovery	550	1,350	2,000	3,250	5,200
Carbon Regeneration	400	850	1,125	1,475	1,800
Chemical Storage	550	1,440	2,700	5,200	9,600
Subtotal	6,480	21,130	39,610	84,375	164,090
Administration Bldg., Site Work-grounds, landscaping, etc. say 10%	648	2,113	3,961	8,438	16,409
TOTAL	7,128	23,243	43,571	92,813	180,499
Use	7,150	23,250	43,600	93,000	180,000

ANNUAL COST OF OPERATION OF OZONATORS

Ozone - Dosage 3 ppm Maximum

say 2 ppm Average

3 ppm x 1.mgd x 8.34 lbs/gal = 25 pounds O_3/d/mgd

Electric load

20.5 ozone tubes/mgd

Assume load is 1.1 kw/tube

Based on Massachusetts Electric Company Rate H, 1 kw-mo would cost $13.43.

$$\text{Cost per mgd} - \frac{2\ \text{ppm}}{3\ \text{ppm}} \times 20.5\ \text{tubes/mgd} \times 1.1\ \text{kw/tube} \times \frac{12\ \text{mos}}{\text{yr}} \times \$13.43/\text{kw-mo.} = \$2425\ \text{yr/mgd}$$

use $2500/yr/mgd

UNIT POWER COST ESTIMATE

Basis: 50 mgd plant - 3900 Kilowatts average demand including high lift pumps

Rate: Massachusetts Electric Company Optional Large-Power Rate H effective January 1, 1974

Peak Demand = 110% of Average - Assumed
1.1 x 3900 4290 kw use 4300

Energy Usage = $3900\text{kw} \times 24 \frac{\text{Hr.}}{\text{Day}} \times 30 \frac{\text{days}}{\text{month}} = 2{,}808{,}000 \frac{\text{kwh}}{\text{month}}$

Demand Charge

0 to 500 kw		= $ 680.00
500 to 4300	=$1.25 x 3800	4750.00
		$5430.00/Month

Energy Charge:

Kilowatt Hours

From	To	Cents kwh	Dollars/Month
0	50,000	2.173	1,086.50
50,000	100,000	1.873	936.50
100,000	860,000	1.573	11,954.80
860,000	1,290,000	1.473	6,333.90
1,290,000	1,720,000	1.023	4,398.90
1,720,000	2,150,000	0.923	3,968.90
2,150,000	2,808,000	0.873	5,744.34
			$34,423.84/Month

Monthly Bill

Demand	$ 5,430.00
Energy	34,423.84
Subtotal	39,853.84/Month
less 2 1/2% High Voltage Metering	- 996.35
Subtotal	38,857.49
less $0.12 per kw Demand for owning transformer = $0.12 x 4300 =	- 516.00
Subtotal	38,341.49
Fuel adjustment @ $0.005/kwh 0.005 x 2,808,000 =	14,040.00
Estimated Monthly Bill	$52,381.49

Monthly Cost per kilowatt = 52,381.49/3900 = $13.43

Annual Cost of Electricity per Horsepower:

$$\$13.43/\text{Month/Kilowatt} \times \frac{12 \text{ months}}{\text{year}} \times \frac{0.747 \text{ kw}}{\text{H.P.}} = \$120.39$$

Use $120/Horsepower/Year

ANNUAL COST OF OPERATION OF ALUM RECOVERY PLANT

ITEM	UNIT	UNIT COST $	10 MGD No.	10 MGD $	50 MGD No.	50 MGD $	100 MGD No.	100 MGD $	250 MGD No.	250 MGD $	500 MGD No.	500 MGD $
Chemicals												
Lime	Ton	50	12	600	60	3,000	120	6,000	300	15,000	600	30,000
Sulfuric Acid	Ton	50	220	11,000	1100	55,000	2200	110,000	5500	275,000	11,000	550,000
Other				600		3,000		8,000		15,000		30,000
TOTAL CHEMICALS				12,200		61,000		124,000		305,000		610,000
Power				3,700		7,500		10,000		15,000		20,000
Trucking & Landfills				2,300		10,500		20,000		45,000		80,000
TOTAL				18,200		79,000		154,000		365,000		710,000

ANNUAL COST OF OPERATION FOR LABOR

CATEGORY	PLANT CAPACITY 10 mgd - 9 persons			50 mgd - 36 persons			100 mgd - 56 persons			250 mgd - 79 persons			500 mgd - 92 persons		
	Pers	$/Pers	Total	Pers	$/Pers	Total	Pers	$/Pers	Total	Pers	$/Pers	Total	Pers	$/Pers	Total
Superintendent	1	17,000	17,000	1	20,000	20,000	1	25,000	25,000	1	30,000	30,000	1	32,000	32,000
Asst. Superintendent				1	15,000	15,000	2	19,000	38,000	2	23,000	46,000	2	24,000	48,000
Chemists				3	12,000	36,000	4	12,000	48,000	6	13,000	78,000	8	13,000	104,000
Ch. Chemist							1	19,000	19,000	1	24,000	24,000	1	24,000	24,000
Chem. Bldg. Operators				4	9,000	36,000	4	9,000	36,000	4	10,000	40,000	4	12,000	48,000
Chem. Bldg. Oper. Assts.							4	7,000	28,000	6	7,000	42,000	8	8,000	64,000
Pump Operators				4	8,000	32,000	8	9,000	72,000	12	10,000	120,000	4	12,000	48,000
													12	9,000	108,000
Stenographer				1	6,000	6,000	2	6,000	12,000	3	6,000	18,000	4	7,000	28,000
Filter Operators	4	9,000	36,000	4	9,000	36,000	4	9,000	36,000	8	10,000	80,000	4	12,000	48,000
													4	9,000	36,000
Mechanics	1	11,000	11,000	5	11,000	55,000	8	11,000	88,000	12	12,000	144,000	4	14,000	56,000
													8	11,000	88,000
Utility Operators	3	8,000	24,000	12	8,000	96,000	16	8,000	128,000	20	9,000	180,000	4	12,000	48,000
													20	9,000	180,000
Supplies & Stores				1	8,000	8,000	2	9,000	18,000	4	9,500	38,000	4	10,000	40,000
Subtotal			88,000			340,000			548,000			840,000			1,000,000
Overhead 25%			22,000			85,000			137,000			210,000			250,000
TOTAL ANNUAL LABOR			$110,000			$425,000			$685,000			$1,050,000			$1,250,000

ANNUAL COST OF OPERATION FOR CHEMICALS

CHEMICAL	ASSUMED DOSAGE-ppm	USAGE lb./MG	COST $/lb.	$/MG
Alum (Make up)	4	33.3	$0.07	$ 2.33
Chlorine	5	42	0.10	4.20
Lime	9.3	77.5	0.04	3.10
Caustic Soda	10	83.4	0.09	7.50
Coagulant Aid	1	8.3	0.55	4.70
Potassium Permanganate	3	25	0.465	11.60

* Based on chemical cost data received during the course of this report preparation for bulk deliveries to the Lowell, Mass. area.

COST PER MILLION GALLONS

CHEMICAL	COST	
Alum	$ 2.33	
Chlorine	4.20	
Lime	3.10	
Coagulant Aid	4.70	
Other	5.70	
	$20.03	use $20.00/MG

Annual Cost - Basis - One million gallons per day

1 x 20 x 365 = $7300/yr./mgd

SUMMARY OF ANNUAL COST OF OPERATION

PLANT CAPACITY

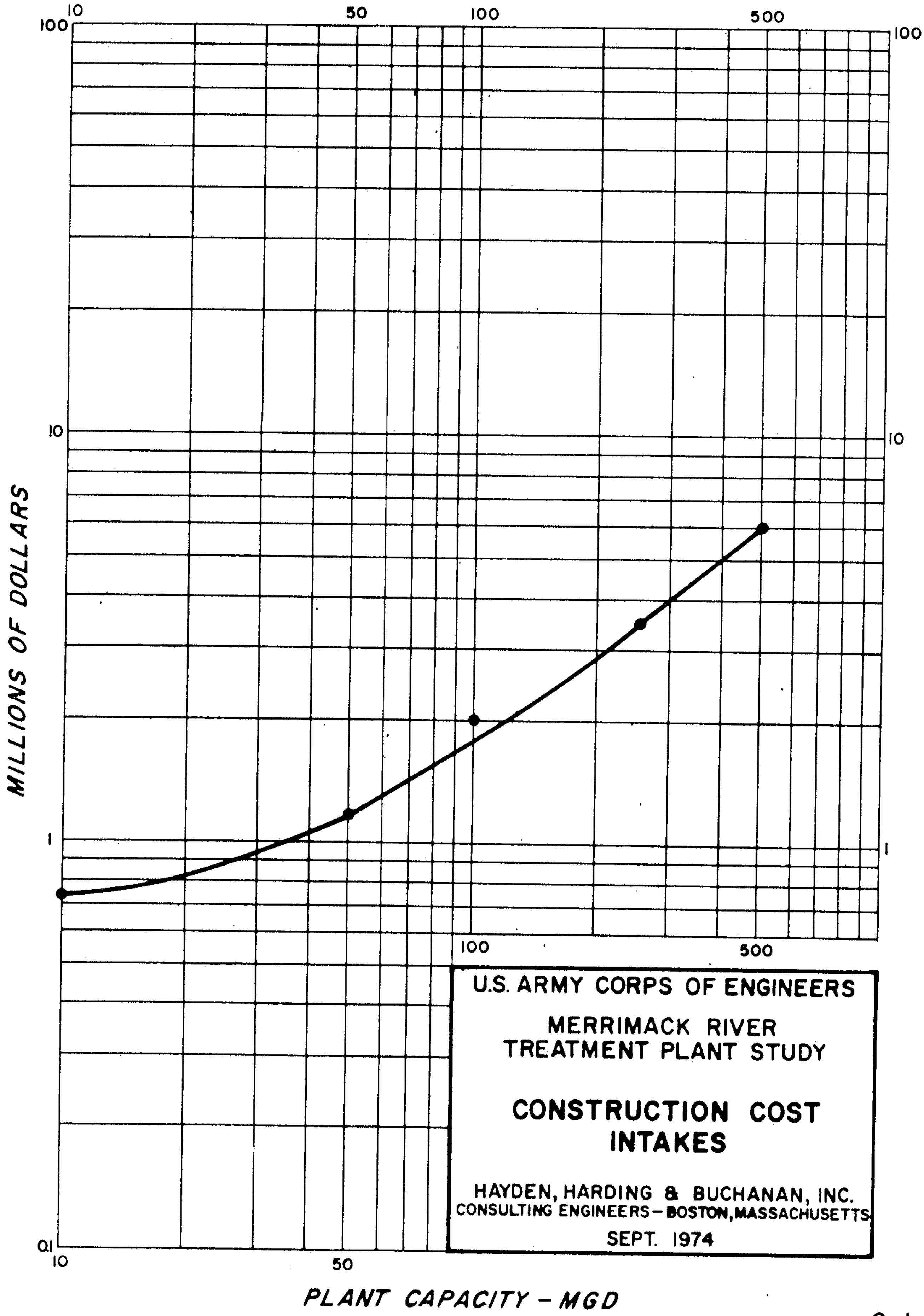
ITEM	10 MGD	50 MGD	100 MGD	250 MGD	500 MGD
	$	$	$	$	$
Ozone @ $2500/yr/mgd	25,000	125,000	250,000	625,000	1,250,000
Power @ $120/yr/HP.					
Raw Water Pumps	11,900	52,800	105,000	258,000	500,000
Rapid Mixing	625	3,000	6,000	15,000	30,000
Flocculation	250	1,200	2,400	6,000	12,000
Sedimentation	1,250	2,400	4,800	7,200	14,400
Filtration	5,000	7,200	14,400	33,600	64,800
Chemical Feeders	1,250	2,400	4,800	7,200	14,400
Miscellaneous	1,725	6,000	12,600	28,000	54,400
Subtotal	22,000	75,000	150,000	355,000	690,000
Alum Recovery Plant	18,200	79,000	152,000	365,000	710,000
Labor	110,000	425,000	685,000	1,050,000	1,250,000
Chemicals @ $7300/ mgd/yr	73,000	365,000	730,000	1,825,000	3,650,000
TOTAL	248,200	1,069,000	1,967,000	4,220,000	7,550,000
Use	$250,000	$1,070,000	$2,000,000	$4,250,000	$7,550,000

TOTAL ANNUAL MAINTENANCE COST

ITEM	MAINT. FACTOR %	10 MGD $	50 MGD $	100 MGD $	250 MGD $	500 MGD $
Intakes						
Building	2	1,500	2,400	4,000	9,000	16,000
Screens	10	10,000	14,500	25,900	32,000	57,000
Gates & Pumps	5	4,500	8,750	13,000	19,750	38,500
Subtotal-Intake		16,000	25,650	42,900	60,750	111,500
Rapid Mixing						
Mixers	10	1,500	3,000	5,000	10,000	19,500
Flocculation						
Flocculators	7	7,000	24,500	49,000	93,800	182,000
Sedimentation						
Sludge Collectors	5	9,500	45,000	87,500	150,000	300,000
Filters						
Mixed Media	5	2,725	5,250	8,750	19,750	35,000
Building	1	4,800	16,320	32,400	72,900	145,800
Equipment	2	3,520	7,000	11,800	19,500	37,700
Subtotal-Filters		11,045	26,570	52,950	112,150	218,500
Alum Recovery						
Building	2	1,200	1,800	2,400	3,000	3,600
Filter Press	7	16,800	33,600	49,000	63,000	87,500
Subtotal Alum Recovery		18,000	35,000	51,400	66,000	91,100
Carbon Regeneration						
Building	2	1,800	4,200	4,800	6,000	7,200
Furnace	5	9,500	20,000	27,500	35,000	40,000
Carbon Reactivation	$0.0025/lb.	175	875	1,750	4,375	8,750
Make up Carbon	35¢/lb.	2,450	12,250	24,500	61,250	122,500
Subtotal Carbon Regeneration		13,925	37,325	58,550	106,625	178,450
Administration & Grounds	2	13,400	42,400	78,600	169,500	328,200
Miscellaneous		1,630	3,155	4,100	11,175	20,750
TOTAL		$92,000	$245,000	$430,000	$780,000	$1,450,000

APPENDIX C

GRAPHS OF COST ESTIMATES



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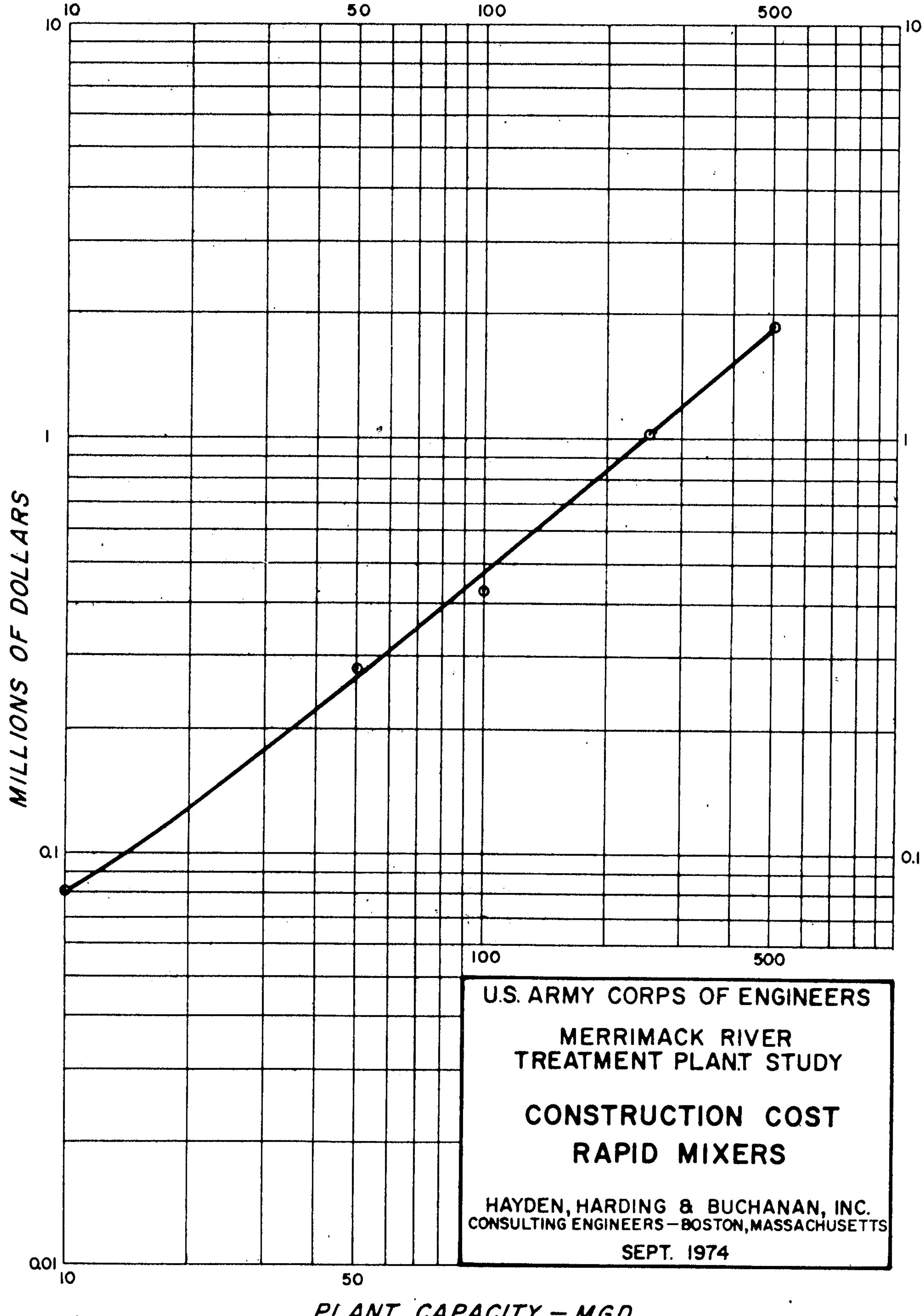
MILLIONS OF DOLLARS
PLANT CAPACITY - MGD
U.S. ARMY CORPS OF ENGINEERS
MERRIMACK RIVER
TREATMENT PLANT STUDY
CONSTRUCTION COST
INTAKES
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS – BOSTON, MASSACHUSETTS
SEPT. 1974



PLANT CAPACITY – MGD

U.S. ARMY CORPS OF ENGINEERS

MERRIMACK RIVER
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CONSTRUCTION COST
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HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS – BOSTON, MASSACHUSETTS

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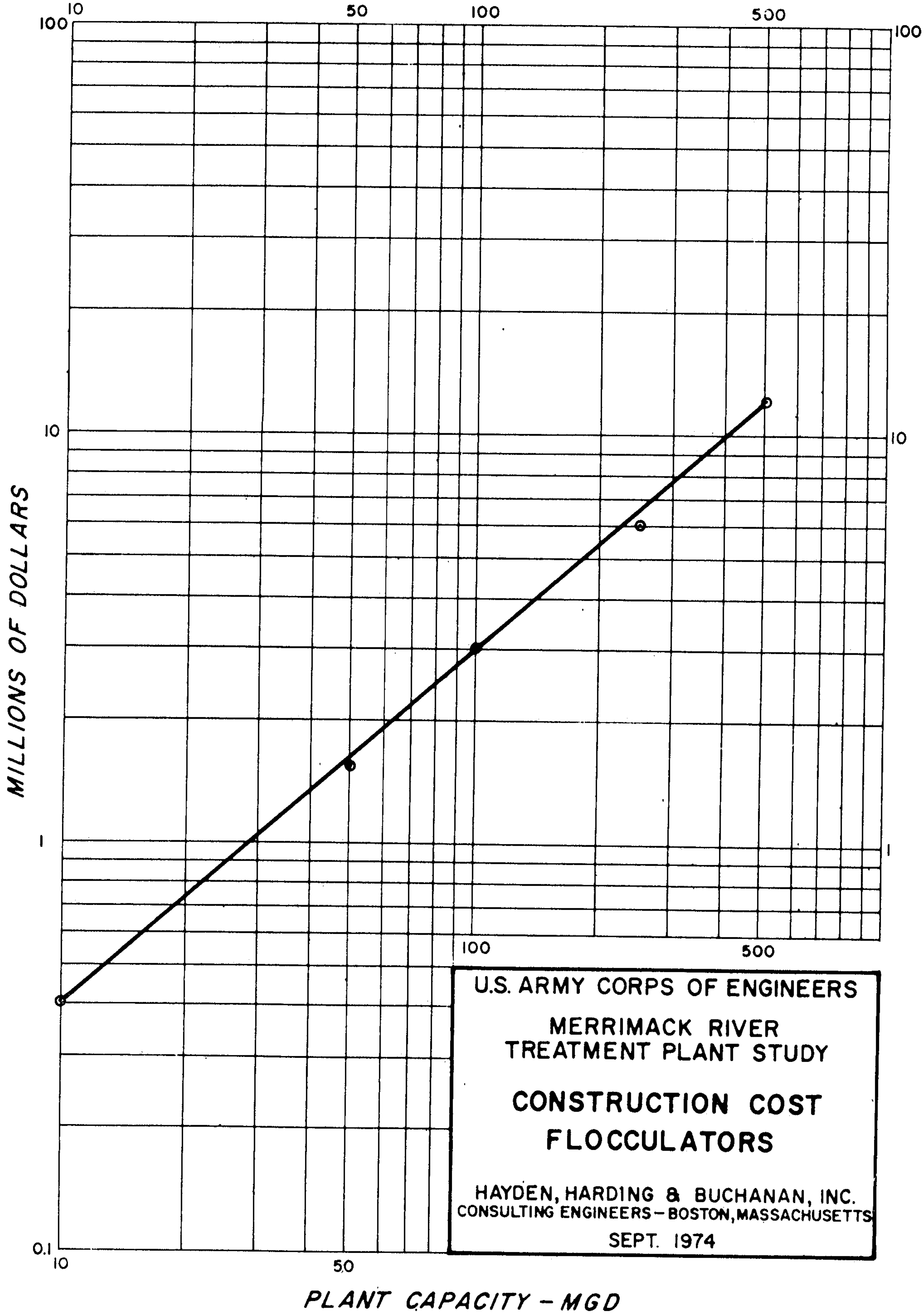

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MERRIMACK RIVER
TREATMENT PLANT STUDY

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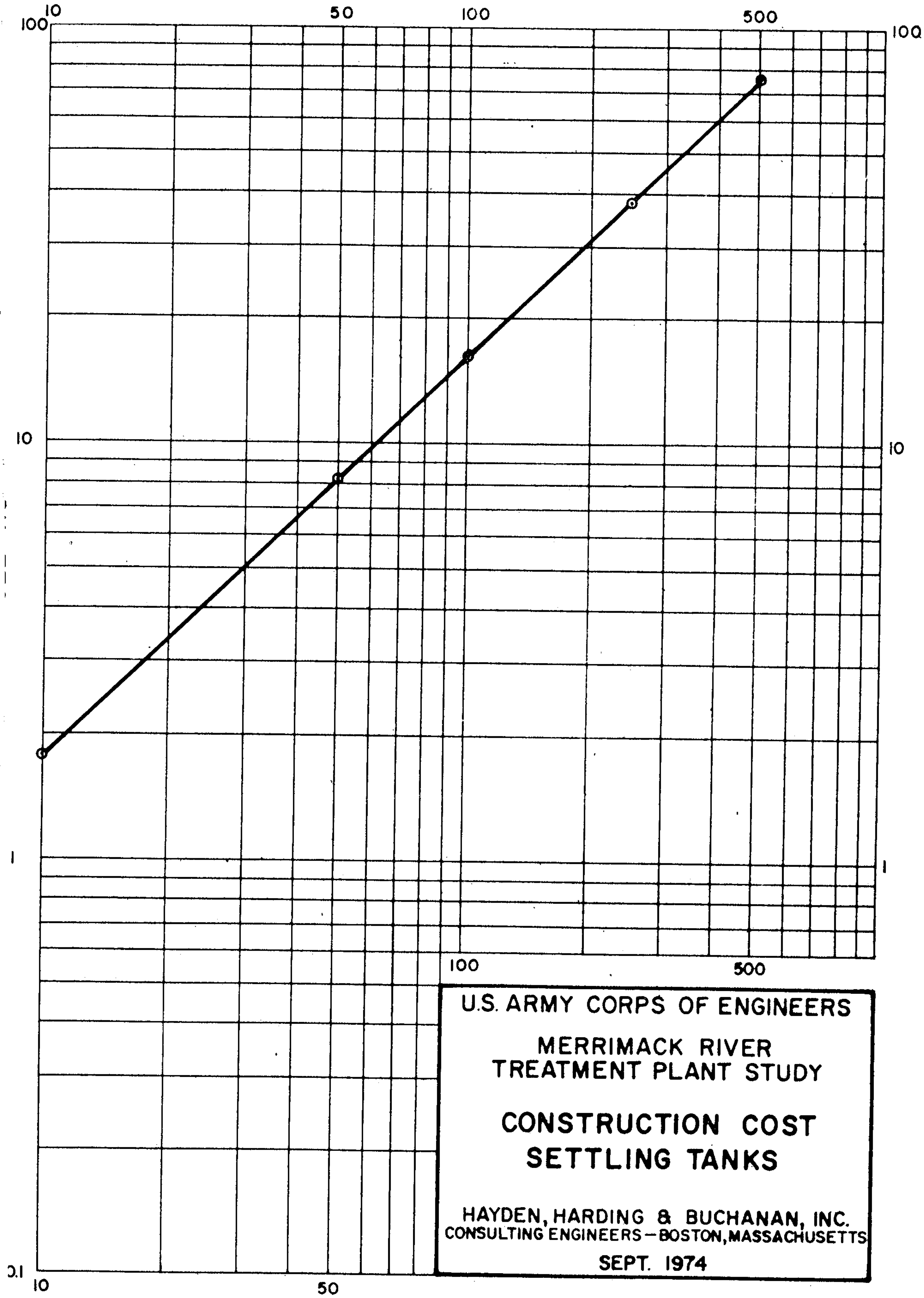
SEPT. 1974



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MERRIMACK RIVER
TREATMENT PLANT STUDY

CONSTRUCTION COST
SETTLING TANKS

HAYDEN, HARDING & BUCHANAN, INC.
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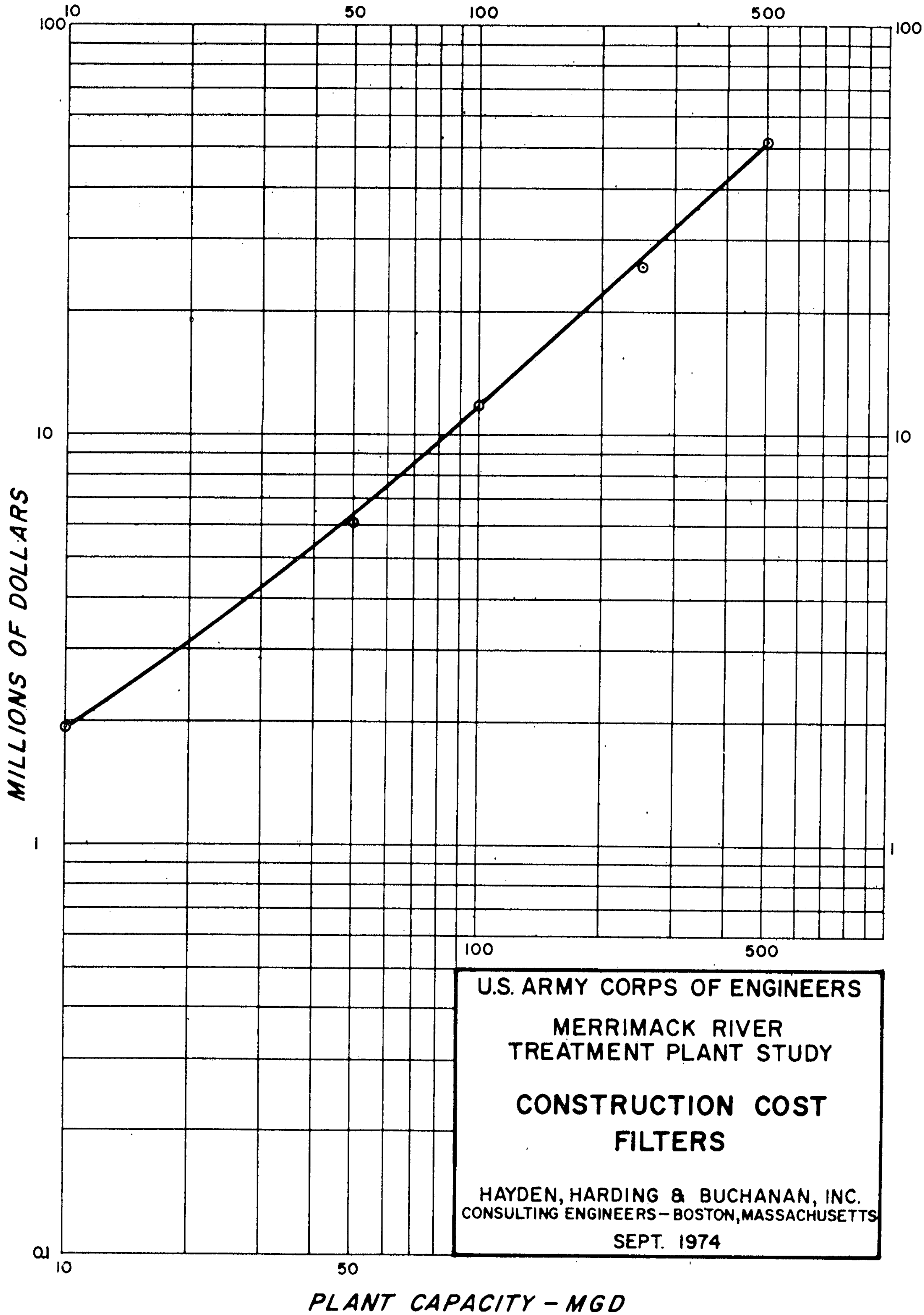
PLANT CAPACITY — MGD



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PLANT CAPACITY - MGD
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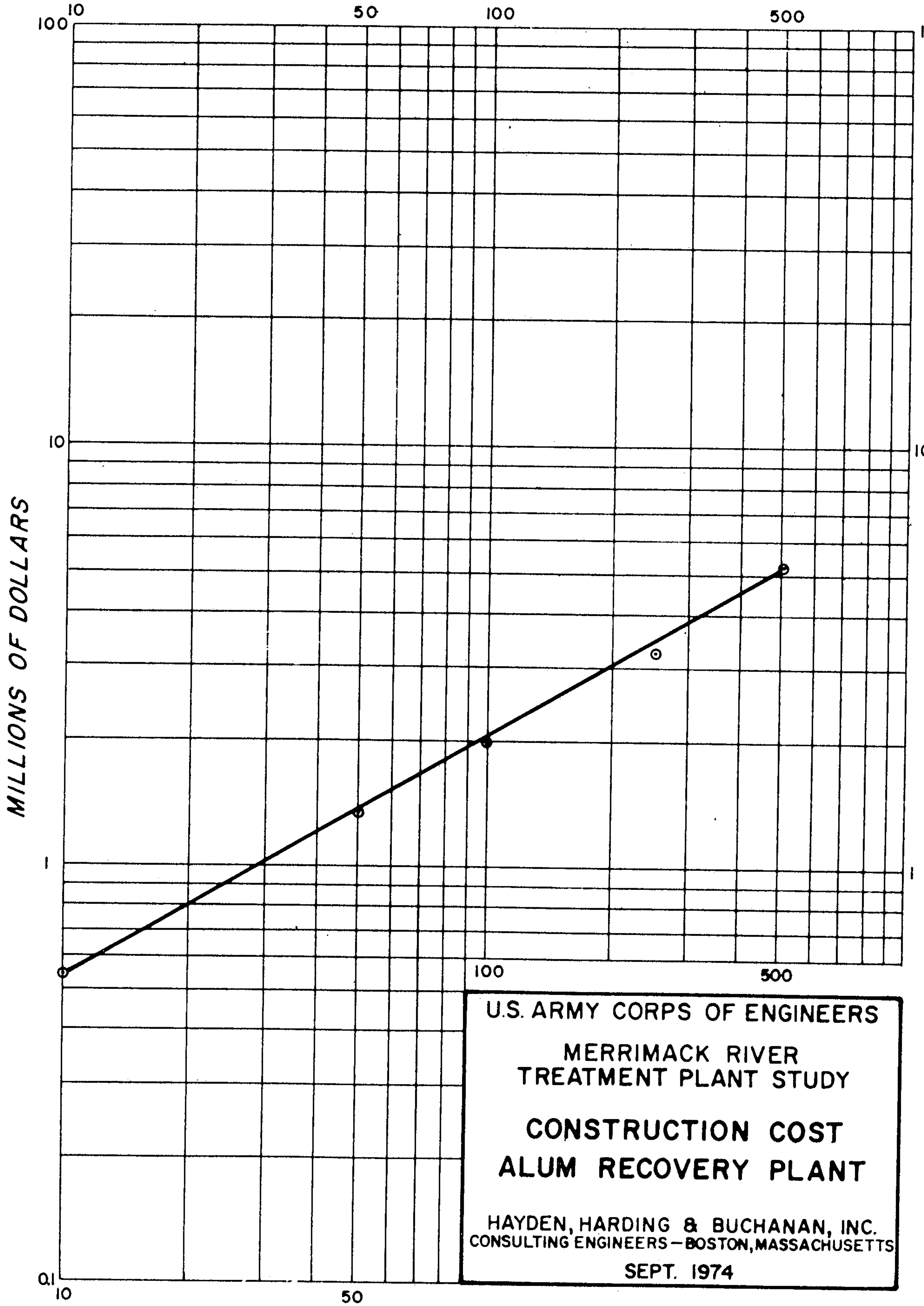
MERRIMACK RIVER
TREATMENT PLANT STUDY
CONSTRUCTION COST
FILTERS
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS - BOSTON, MASSACHUSETTS
SEPT. 1974



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TREATMENT PLANT STUDY

CONSTRUCTION COST
ALUM RECOVERY PLANT

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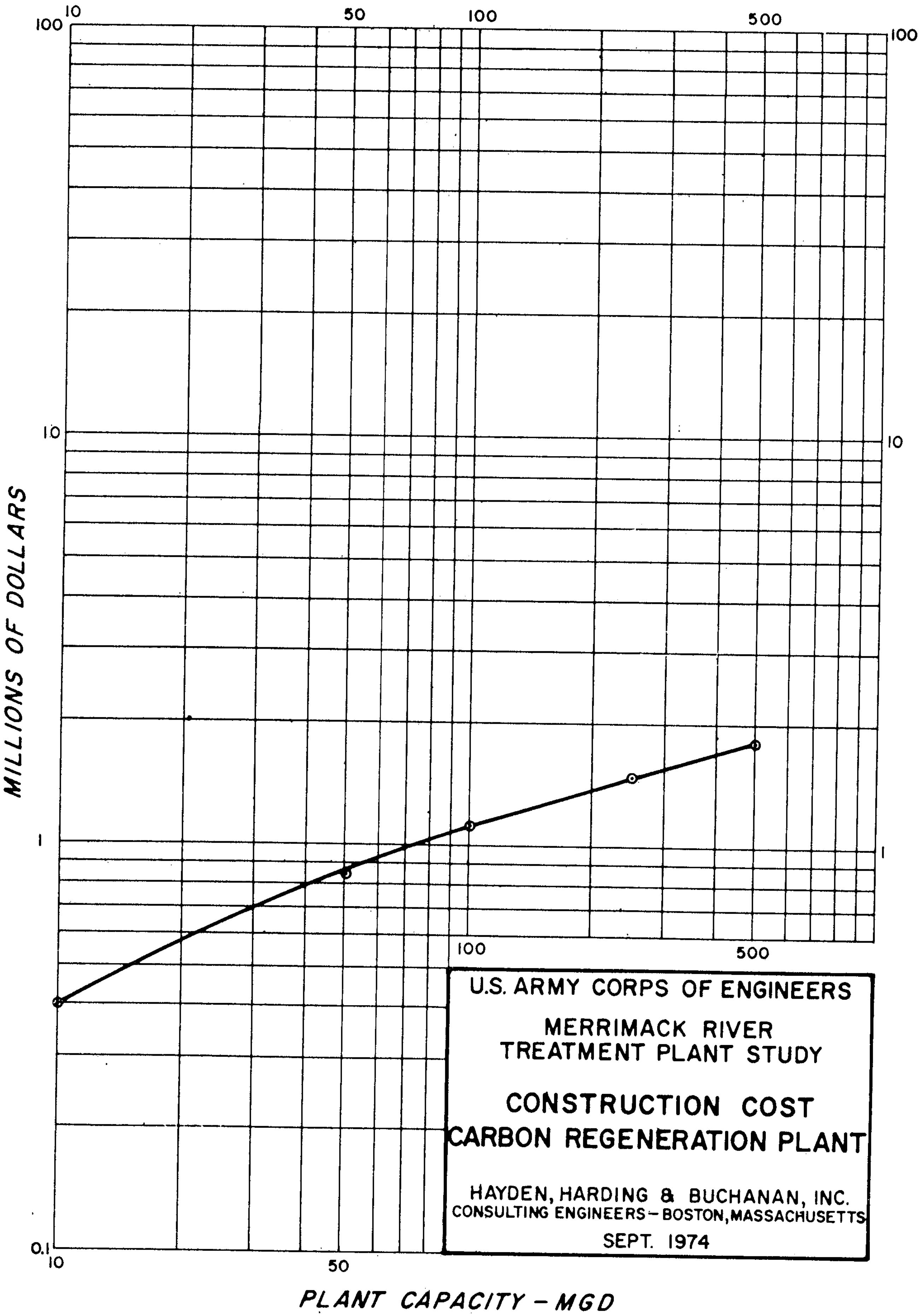
PLANT CAPACITY – MGD



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MERRIMACK RIVER
TREATMENT PLANT STUDY

CONSTRUCTION COST
CARBON REGENERATION PLANT

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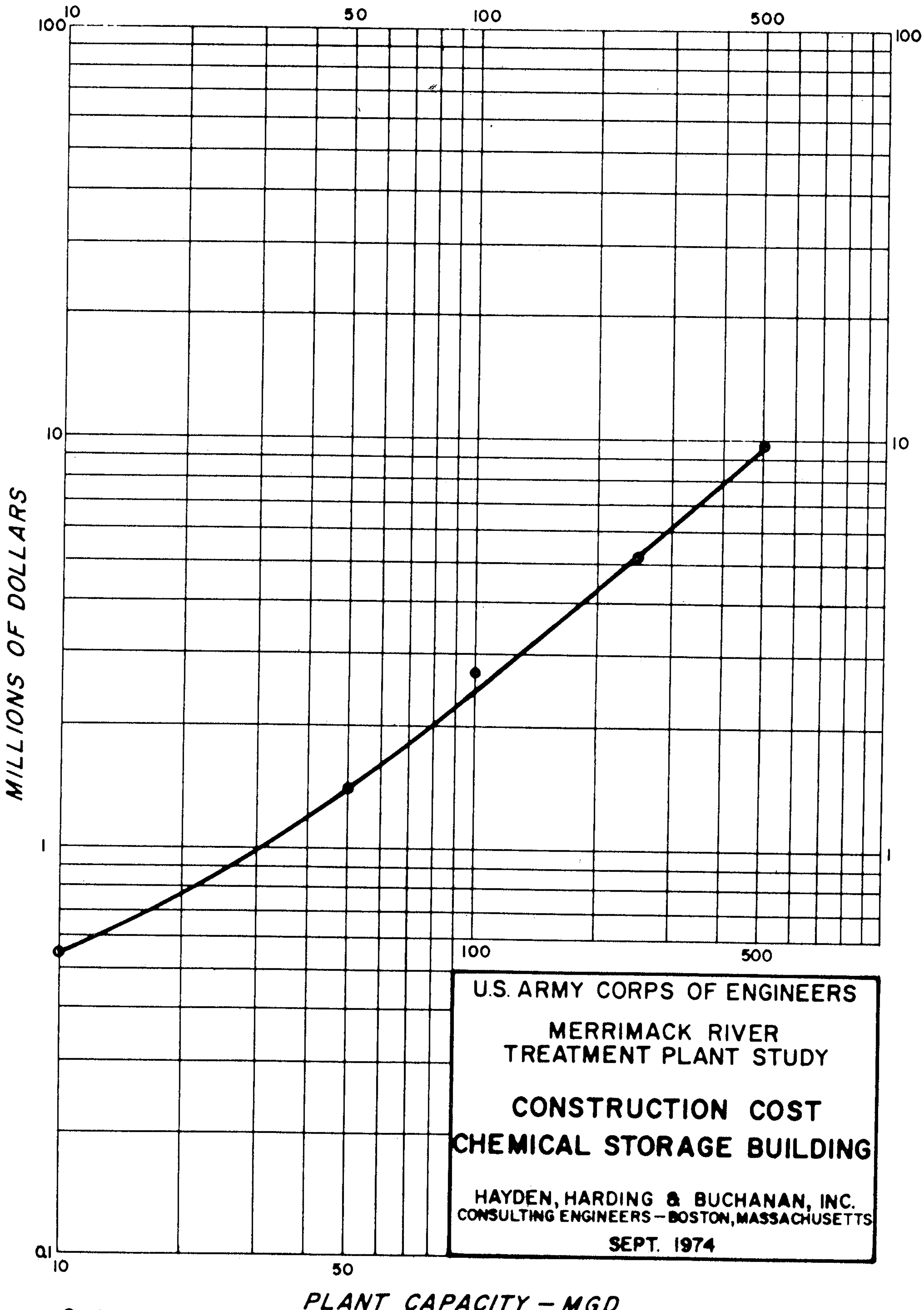

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MERRIMACK RIVER
TREATMENT PLANT STUDY

CONSTRUCTION COST
CHEMICAL STORAGE BUILDING

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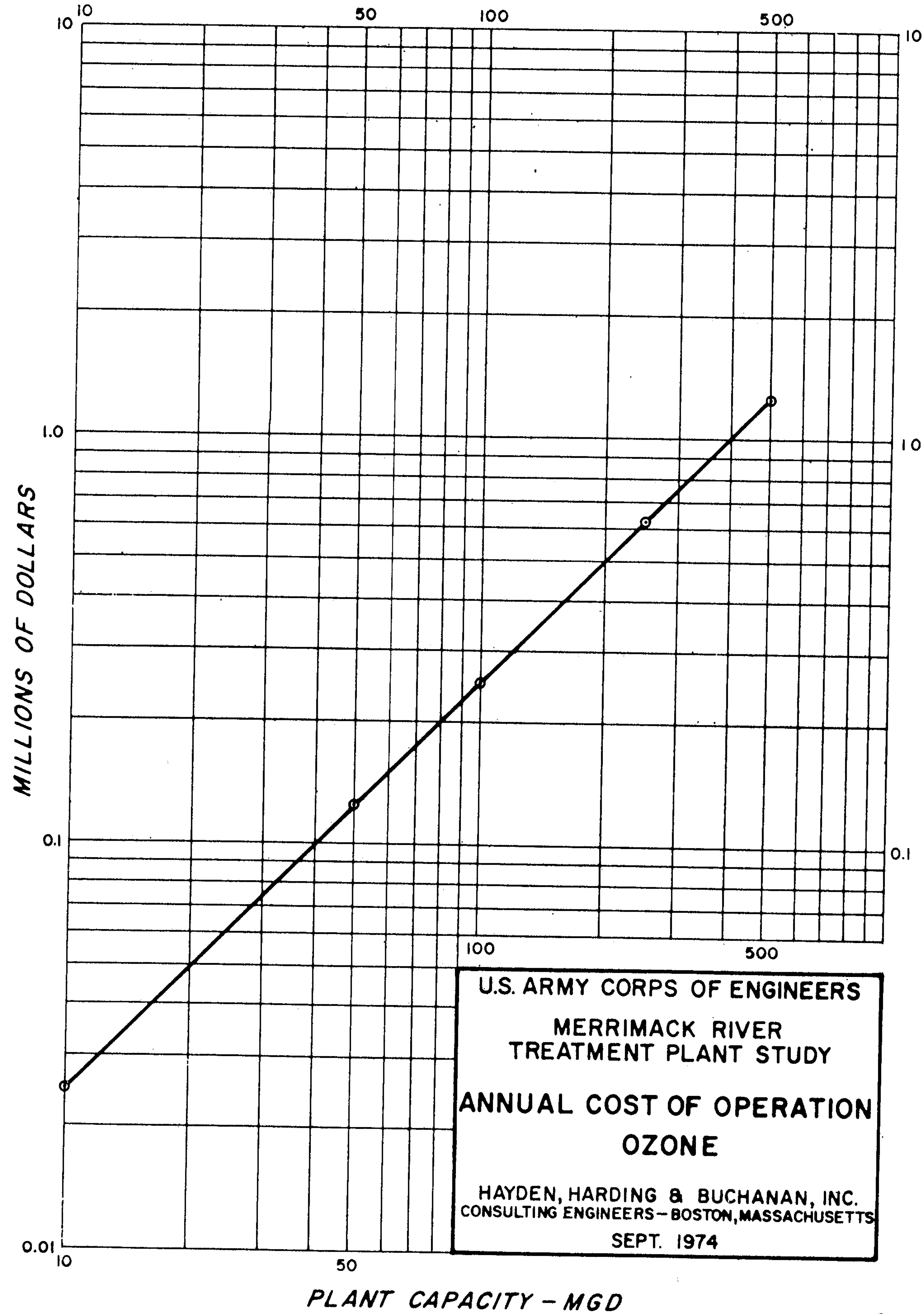
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MERRIMACK RIVER
TREATMENT PLANT STUDY
ANNUAL COST OF OPERATION
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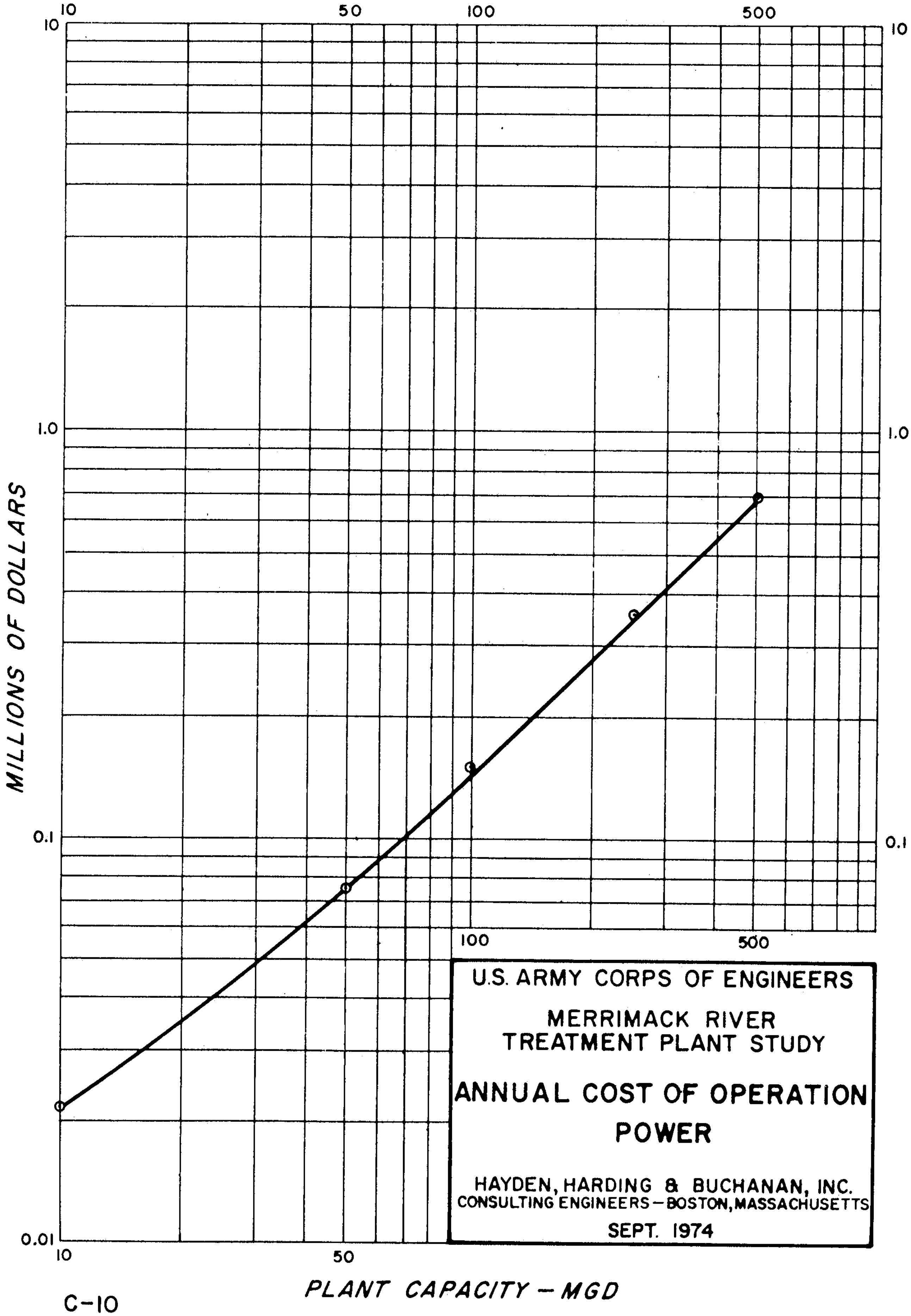
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS – BOSTON, MASSACHUSETTS
SEPT. 1974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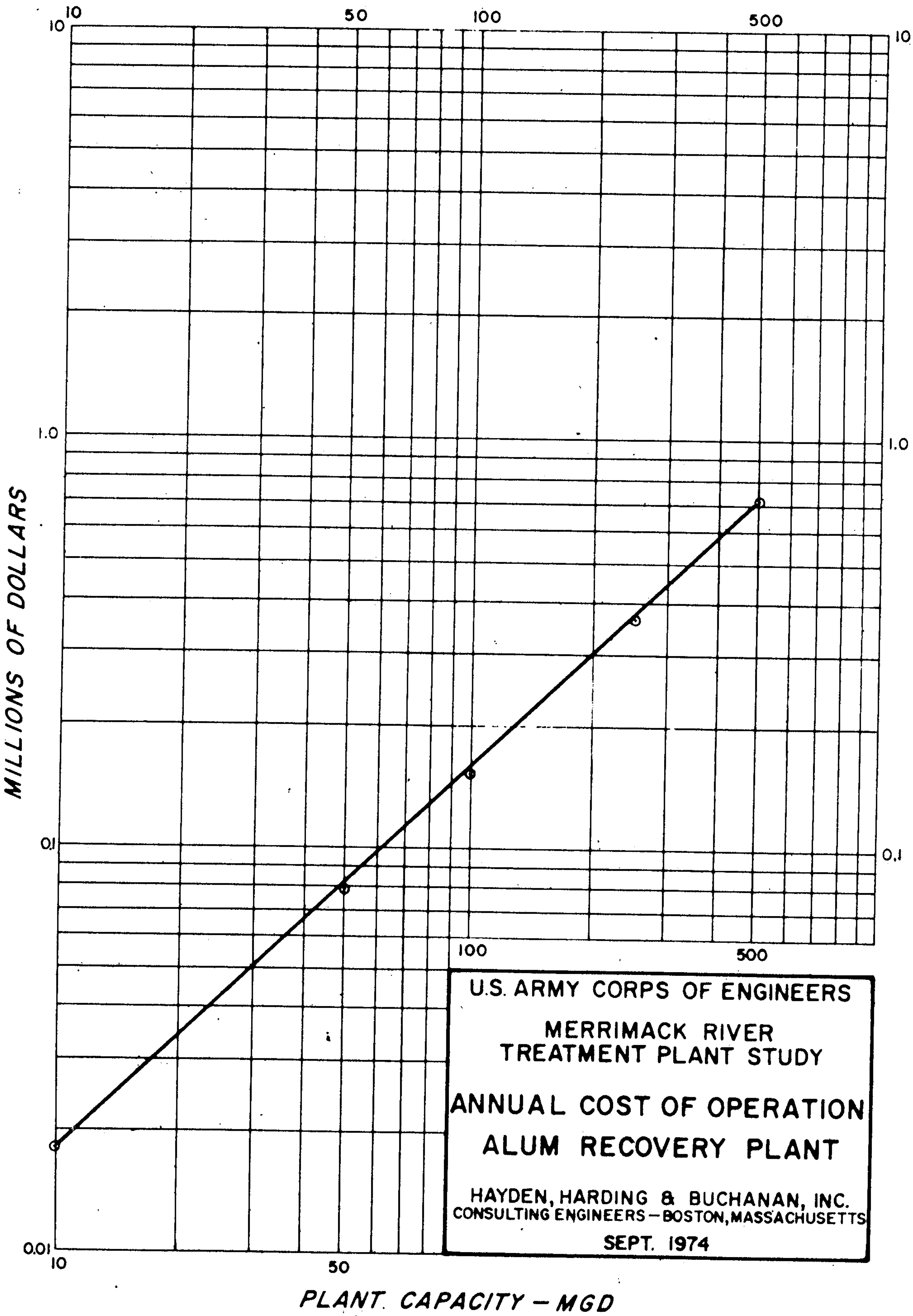
PLANT CAPACITY — MGD
U.S. ARMY CORPS OF ENGINEERS
MERRIMACK RIVER
TREATMENT PLANT STUDY
ANNUAL COST OF OPERATION
POWER
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS — BOSTON, MASSACHUSETTS
SEPT. 1974



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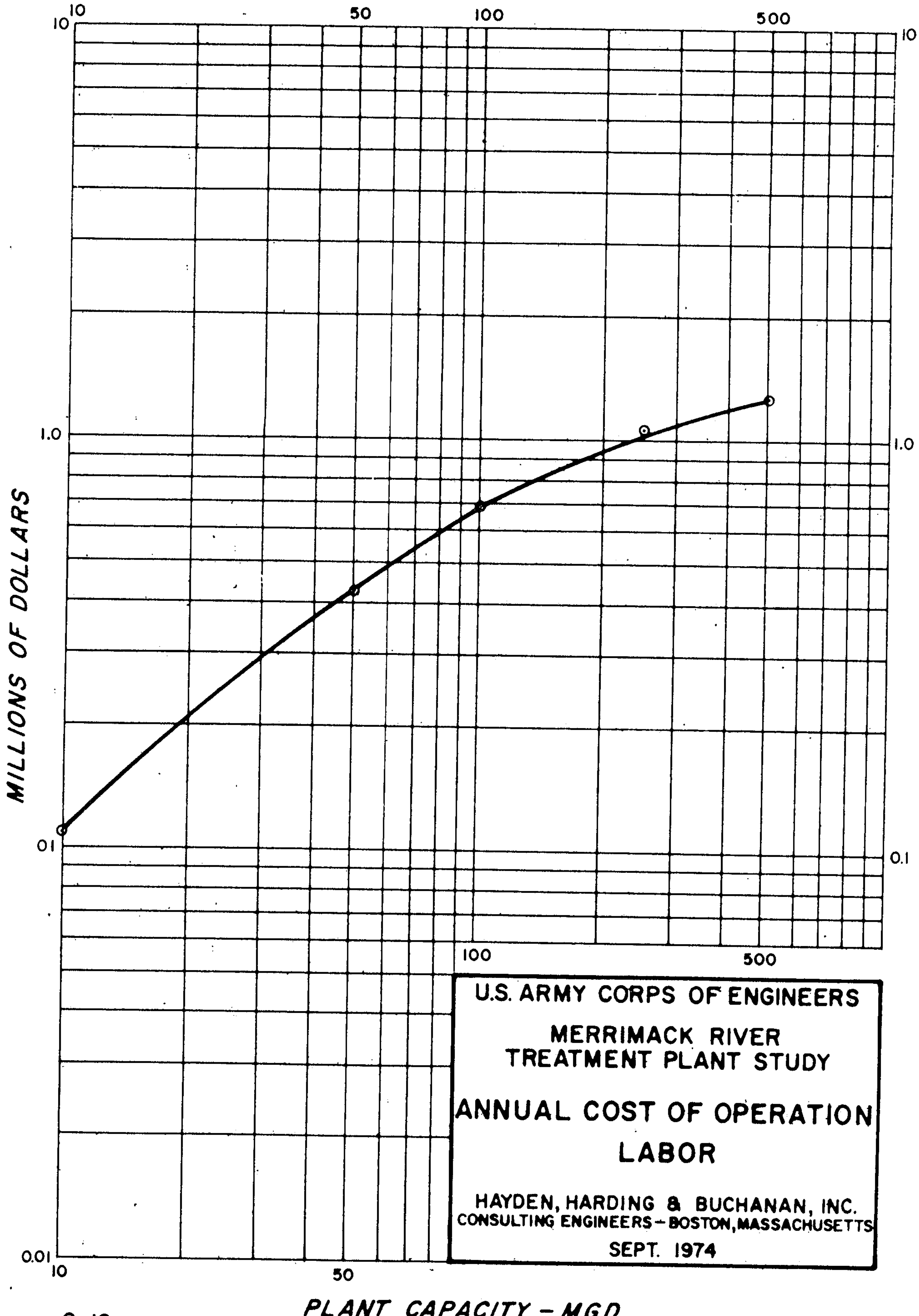
MILLIONS OF DOLLARS
PLANT CAPACITY — MGD
U.S. ARMY CORPS OF ENGINEERS
MERRIMACK RIVER
TREATMENT PLANT STUDY
ANNUAL COST OF OPERATION
ALUM RECOVERY PLANT
HAYDEN, HARDING & BUCHANAN, INC.
CONSULTING ENGINEERS — BOSTON, MASSACHUSETTS
SEPT. 1974



U.S. ARMY CORPS OF ENGINEERS

MERRIMACK RIVER
TREATMENT PLANT STUDY

ANNUAL COST OF OPERATION
LABOR

HAYDEN, HARDING & BUCHANAN, INC.
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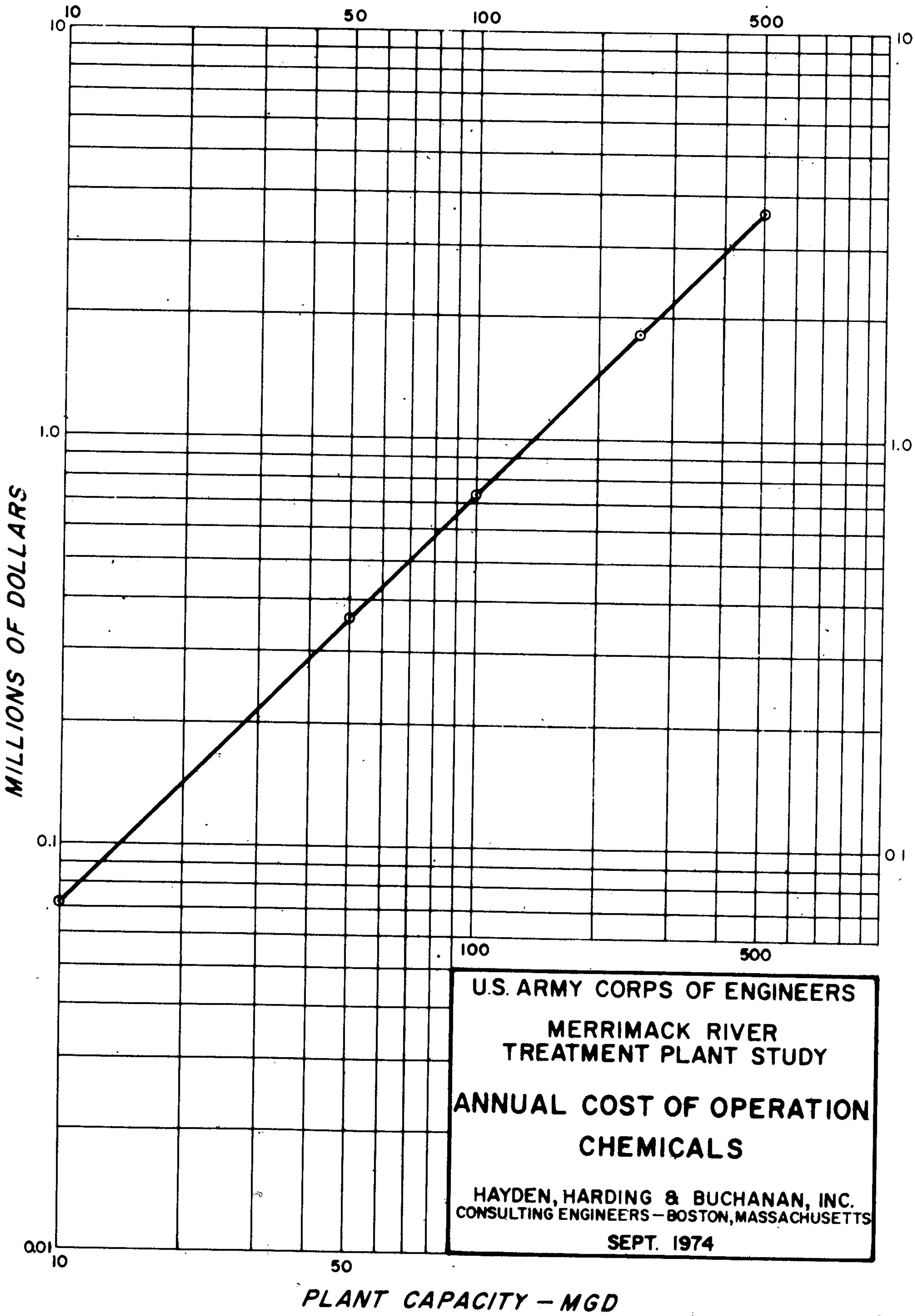

U.S. ARMY CORPS OF ENGINEERS

MERRIMACK RIVER
TREATMENT PLANT STUDY

ANNUAL COST OF OPERATION
CHEMICALS

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CONSULTING ENGINEERS – BOSTON, MASSACHUSETTS
SEPT. 1974

APPENDIX D

BIBLIOGRAPHY

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